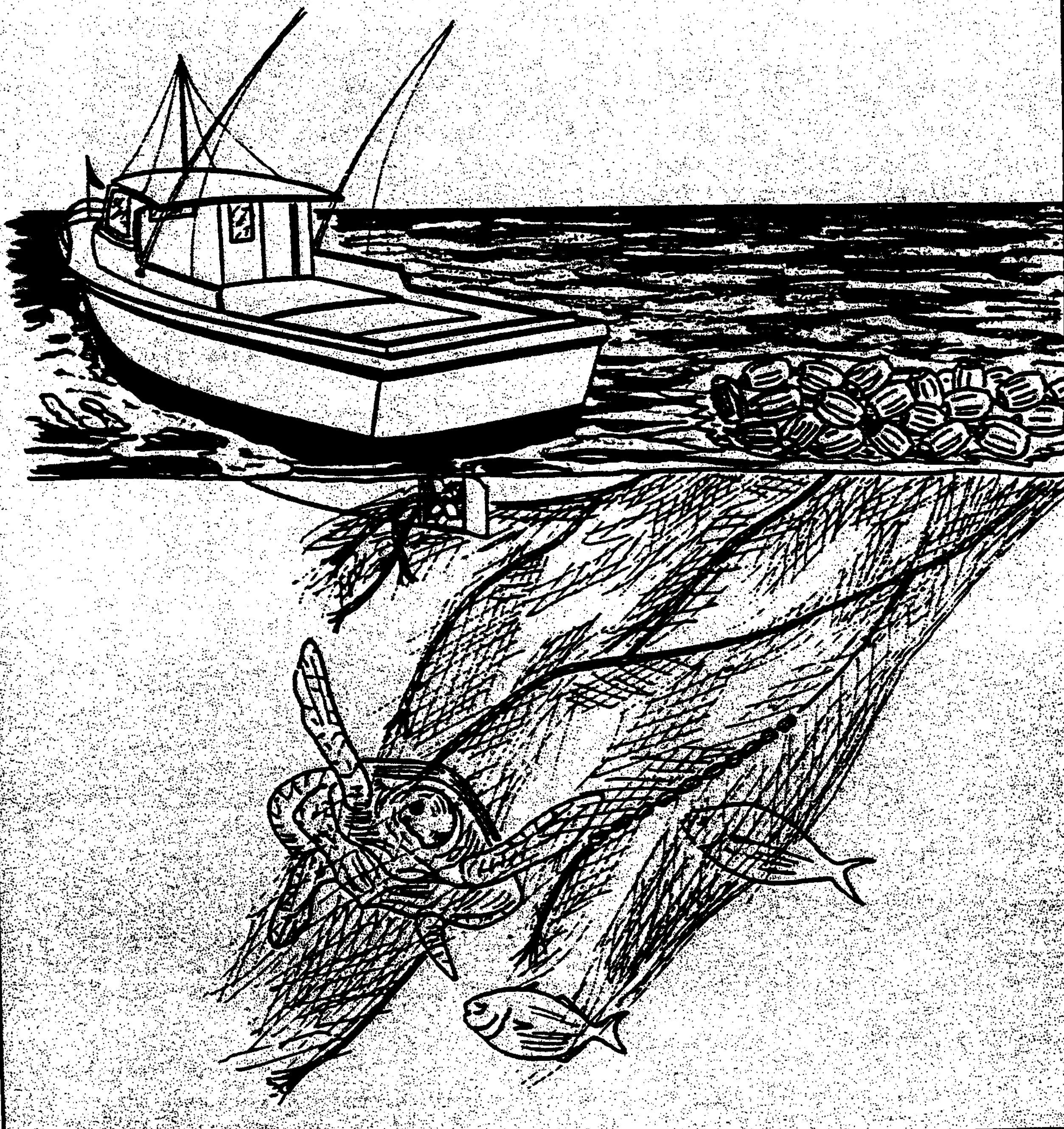
SESSION II

IMPACTS OF DEBRIS ON RESOURCES



DEBRIS ENTANGLEMENT IN THE MARINE ENVIRONMENT: A REVIEW

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ABSTRACT

A review of the literature shows debris entanglement is now evident for many species in all oceans of the world. Types of debris range from large intact fishing nets to small plastic fragments of unidentifiable origin. Nonbiodegradable plastic objects form a large portion of the debris. The term entanglement herein covers interactions with objects by ingestion and by encirclement or snagging of body parts in netting and loops. Behavior leading to entanglement is categorized as accidental, indiscriminate, or deliberate. Birds, fish, and sea turtles become weakened or die from both types of entanglement, through accidental or indiscriminate encounters. Marine mammals suffer primarily from encirclement through accidental catch in nets, indiscriminate hauling out on balls of netting, and deliberate playing with loops and openings; they die from increased drag and severed tissue. Humans are harmed primarily by snagging of objects during ship operation and underwater activity. Significant ecological harm is occurring in certain areas and species. Significant commercial loss may be occurring through fish mortality and ship hazards.

Beach deposition, sinking, and environmental degradation are possible natural removal mechanisms. Potential human removal mechanisms are a complete halt to dumping, retention of caught debris, and beach clearing.

INTRODUCTION

The use of nonbiodegradable material in fishing gear, containers, packaging, and objects has become commonplace throughout the activities occurring in the marine environment. Disposal of these materials at sea has resulted in significant mortality in birds, fish, marine mammals, sea turtles, and possibly humans. This entire problem has been referred to as debris entanglement: The unintentional harassment, injury, and mortality of organisms through physical means by objects of foreign material in the marine environment. Entanglement includes ingestion, primarily of small particles, and wrapping, snagging, or encirclement of body parts by debris.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

Debris entanglement can occur either in abandoned netting or simple trash. Incidental entanglement in nets actively used for fishing is discussed elsewhere.

SOURCES

Marine debris consists of a range of objects, reflecting the entire spectrum of substances used in modern society including glass, metal, wood, rubber, and plastic. Plastic causes the major portion of harm, is the longest-lasting substance, and is the most important of these in debris "pollution."

In certain areas such as the Bering Sea, near major fishing grounds and not near shipping lanes, the vast majority of persistent plastics appears to originate with the fishing industry (Merrell 1980). This includes discard of whole fishing gear, fragments of netting, and a range of plastic trash. It is estimated that in 1980, debris from the fishing industry alone was being dumped into the Bering Sea at 1,361 metric tons (MT) (3 million pounds) per year. Discarded net fragments from this industry in the Bering Sea was estimated at 145,000 pieces per year (Merrell 1984). The worldwide rate for 1975 from the fishing fleet was 23,587 MT (52 million pounds) of plastic packaging material discarded, and 135,172 MT (298 million pounds) of plastic fishing gear, including nets, lines, and buoys (National Academy of Sciences 1975).

Discarded netting ranges from whole nets down to small fragments of several ounces. The high seas salmon gill net fishery of the North Pacific sets 8- to 10-nmi long nets, and the squid fishery sets 18- to 20-nmi nets. At least 15,000 nmi of drift gill net are used each day in the North Pacific. All of this has potential for loss, tear, abandonment, and accidental catch on the bottom. In addition, at least a large portion of gill nets wear out after 1 year of use, leading to discard of thousands of miles of net each year (U.S. Department of Commerce 1984).

In other areas, where general shipping is the dominant offshore industry, the majority of plastic debris appears to originate with the merchant fleet industry (Dixon and Dixon 1981). This is confirmed by Shaughnessy (1980) in an increase in Cape fur seal entanglement during decline of fishing industry. Approximately 71,000 ships were in operation in 1979, according to Lloyd's of London. Each crewmember disposes of 1.1 to 1.6 kg of refuse per day, plus 290 MT per ship per year of cargo-associated waste. The solid waste from this fleet amounts to 6.5 million MT per year for marine litter from the merchant fleet (Horsman 1982). From these figures, it appears the merchant fleet may be a source of as much or more plastic than the fishing industry. The total discard for merchant ships was estimated at 590 MT per year (1.3 million pounds per year) (Dixon and Dixon 1981) of total solid waste, about four times the weight of the fishing industry's plastic waste. It is not clear what the contents of shipboard trash may be, although Horsman (1982) presents an in depth analysis for two ships. Nonbiodegradable material accounted for 26-30% of total ships' waste, including glass and metal, so the fishing and merchant fleet plastic contribution may be about equal.

Trash for our purposes includes any object of foreign material, usually of plastic, except netting. Monofilament lines, rope, twine, packing bands, both for the fishing industry and cargo ships, floats, plastic baggies, beer six-pack holders, lifejackets, and styrofoam packing pellets are some examples. Horsman (1982) estimated 639,000 plastic containers are discarded daily into the sea, along with other items. This was based on an average of 30 people per ship. These figures do not include navies, however, which have, for example, floating cities of 5,000 people on each aircraft carrier. Pleasure boats, research vessels, and oil tankers also contribute large amounts of trash (National Academy of Sciences 1975). Venrick (1973) confirmed this scale of the discard problem with a pelagic survey estimating 5 to 35 million plastic bottles on the surface of the North Pacific from direct sampling.

Land sources such as coastal factories have generally been concluded to be the source of the small (2-5 mm) "raw" plastic pellets or beads. About the size of the head of a match, these are regularly shaped, rounded pellets from intermediate processes in the plastics industry. Colton et al. (1974) suggested that the plastics industry itself may be the source of this debris in the rivers, estuaries, and coastal waters of the United States. Studies showed concentration of up to 21 items per 2.5 cm^3 in sediments downstream from factory outlets, and deposition in sediment continued downstream into estuaries. Surface concentrations of 101-250 g/km^2 were found several hundred miles offshore, indicating that river dumping of this plastic leads directly to pelagic plastic pollution. Carpenter and Smith (1972a) identified this problem in the Sargasso Sea (3,500/km^2), Hays and Cormans (1974) found the source by sampling factory effluent, Colton et al. (1974) demonstrated wide distribution off North America, Kartar et al. (1973, 1976) for the United Kingdom, Gregory (1977) for New Zealand beach concentrations at maximum of 100,000/lineal meter, Van Dolah (1980) for the Gulf Stream, Shiber (1979, 1982) near eight factories in Spain and for Lebanon, and Wong et al. (1974) for the Pacific (34,000/km^2 maximum). The New Zealand beaches have been described as covered with "plastic sand." The plastics industry, through the Plant Emission Study of the Society of the Plastic Industry, concluded to the contrary that factory effluent was not responsible.

The scientific commentaries above on pellet sources could be partly challenged by Morris' (1980b) South Atlantic survey. Aside from a probable misinterpretation of the rounded ends as evidence of weathering, he presents excellent data suggesting these pellets are now a ubiquitous, high-density worldwide contaminant to the extent that the source is now unimportant. He found 1,000-2,000/km^2 on average in the Cape Basin of the South Atlantic. This constancy throughout the world is confirmed by sampling in the North Pacific (Wong et al. 1974) which found a maximum of 34,000/km^2 including a distinct concentration peak in the eastern Pacific, and Rothstein's (1973) discovery of the same pellets from Leach petrel stomachs in 1962. He points out that these pelagic birds feed not only in the open ocean, but avoid the Sargasso Sea, indicating widespread distribution of pellets outside of low wind stress areas, even before the current sampling device, the neuston net, was invented.

The sources are not at all clear for the small, jagged particles of all sizes also now found around the world. Rothstein (1973) notes many of these particles were also found in Leach's petrels in 1962. They are undoubtedly the result of the breakup of plastic trash, but the sources of the trash are not clear. Higher concentration offshore even in industrialized areas indicates they are not shore-produced (Van Dolah et al. 1980). Morris (1980a) gives a density of 2,000/km^2 in the eastern Mediterranean for plastic pieces larger than 1.5 cm. Given the tremendous worldwide concentration of these pieces, until an estimate is made of the origin of these pieces, it would perhaps not be wise to allow ourselves the simple conclusion either of fishing or merchant fleet discard as the largest source of persistent plastics.

The source of elastic threads (rubber "offcuts") found in puffins on the coast of England and Scotland and around the necks of dogfish off Norway has not been identified. They may come from the garment industry. If so, they appear to have come from the European Continent, or be the result of illegal dumping in Great Britain. There appears to be no reason to ignore the notion the thread could have floated from the continent to the British coast, since there is no particular reason for them to sink.

The possibility that beach debris is produced by "picknickers" seems to have been put to rest. Scott (1972) in a study specifically aimed at this question, concluded from the condition, markings of origin, time and place of observation that the contribution of "picknickers" to shore litter was minimal relative to sea deposition. Dixon and Dixon (1981) and Merrell (1984) also confirmed this, Merrell by selecting a spot virtually inaccessible and quite unappealing to recreational bathers, Amchitka Island.

FATES

Since the plastic in netting is of either positive or neutral buoyancy, discarded netting generally stays suspended at the surface. Plastic and glass floats also usually stay at the surface.

When suspended, large pieces of net and monofilament line often "ball up." Balls of up to 9.1 by 30.5 m (30 by 100 ft) have been sighted. Monofilament line may wrap around other objects, providing more opportunities in loops and twists for entangling. Netting which has caught on the bottom, either causing abandonment or after discard, will stay vertical in the water if the floats are still attached. Sometimes these floats have considerable buoyancy and keep a large net "hanging" like a curtain for years. The nets will also, of course, stay vertical and continue to drift if they still have their floats and are not caught on the bottom. Most of this plastic at the surface is lightweight polypropylene and polyethylene. Abrasion or "crazing" of the surface of the debris may evidence a long time in circulation.

Other plastic material sinks partly or completely through the water column depending on its density. Medium-weight pieces (possibly polystyrenes, styrene copolymers) are thought by Morris (1980a, 1980b) to stay suspended in the water column, in the colder, denser layers. Heavy pieces (such as acrylics, cellulosics, substituted polymers, vinyl polymers) are found on the bottom, along with glass floats, netting, crab pots, wire, cans and metal fragments, cloth, synthetic rope, and twine, etc. (Feder 1978). The variation in the water column for the same type of objects has not been investigated or explained.

Dixon and Dixon (1981) holds that most debris begins its journey with deposition within 400 km of land. Wong et al. (1974) also found a much wider range of debris close to land; papers, elastic bands, and wood were present only up to 500 nmi from shore. Carpenter and Smith (1972b) found a much greater range of plastic types within several hundred miles of shore, and Morris (1980b) found only the lightest plastics, polypropylene, and polyethylene in the open ocean far from any sources. The accumulation of abandoned net at this time seems particularly concentrated in the Bering Sea, most likely because of its tremendous fishing fleets (Merrell 1985). Plastics and styrofoam sheeting are the other types of debris found in the open ocean. The small pellets or beads in particular seem to occur quite far from their probable source, in accord with other indications of having been at sea for a long time. On the other hand, one must note generally the lack of midcolumn and benthic research in these pelagic areas for the deep waters and nonfishing areas.

Plastic and other debris has been shown in several studies to follow the standard pattern of drifting particulates at the surface, influenced by wind and current. It moves with major currents until slowing down with the current and little wind pressure. A significant concentration is evident along long. 143°W of the eastern North Pacific, where the North Pacific Current slackens, and other debris such as tar balls is known to accumulate.

Wong et al. (1974), in their track eastwards along lat. 35°N (roughly Tokyo-Los Angeles), found that plastic, although widespread throughout the Pacific, was relatively absent in the western Pacific, completely absent at long. 125°W, had a huge peak of accumulation in the eastern Pacific at long. 143°W (coinciding with zero annual wind stress), and smaller peaks in areas of the broad, slacker subtropical current from the western Pacific. Shaw and Mapes (1979) also found the dominant factor of low net wind stress southwards along long. 158°W. In interpreting the more southerly distribution of plastics, combined with Wong et al.'s easterly concentration, Shaw and Mapes suggest sources in the western Pacific and the eastern Pacific and, a fairly long lifetime in the water, in contrast to Wong et al.'s suggestion of a possible large contribution by Hawaii.

The Atlantic studies generally confirm the overall widespread distribution and significant influence by currents. Van Dolah et al. (1980) showed likely entrainment in the Gulf Stream, and Winston (1982), from the sources of debris on a Florida coast, found evidence of entrainment in the Guiana, Antilles, and Caribbean Currents. From Carpenter's (1972a, 1972b) direct sampling of the Sargasso Sea surface, and Winston's sampling of debris in Sargassum rafts washed ashore in Florida, considerable accumulation is indicated in this low wind stress area, and in the windrows at the edges of convection cells.

Netting debris has also been reported on the coast of an island just off the Antarctic continent. Gajardos (pers. commun.) saw a net fragment on South Shetland Island at the north tip of the Antarctic Peninsula, close to the circumpolar current.

The length of time this debris remains in the ocean appears quite variable, from days to decades. The upper limit is most likely the ghost nets completely submerged in cold water, since they are most resistant to degradation and are exposed to the minimum of light, heat, and abrasion. It is not known how long the plastic material survives under these conditions. Wehle and Coleman (1983) indicate plastic particles on beaches may last 5 to 50 years, so the upper limit for sunken nets is most likely above 50 years.

Dixon and Cooke (1977), using detailed dating techniques of containers in a beach survey in confined waters close to the heavily traveled Straits of Dover, showed that 83% were <2 years old and 87% <3 years, indicating fairly quick removal from the sea surface (not necessarily by beach deposition). In a controlled release experiment from a nearby city, 69% of containers were beached within 24 days. This rapid removal is confirmed by my winter beach survey in Argentina of a completely clean 100 m of beach, and only two synthetic fragments in 1 km. A local biologist (Lopez pers. commun.) said the beaches have considerable continuous debris during the summer when fishing vessels are offshore.

Merrell (1984) generally confirms this rapid rate of removal: Decreased foreign fishing effort resulted in decreased beach litter in the Bering Sea. Although the total reduction in fishing vessels is not clear from Merrell's work because of inclusion of only foreign vessels, a significant discrepancy between reduction of foreign trawl vessels (66%) and reduction of trawl-web accumulations (37%) could show that 1) debris discarded in open ocean far from shore takes considerable time to drift in and be deposited, or 2) that netting drifts more slowly than containers, or 3) that number of discards per vessel increased though weight decreased, or 4) that the same vessels are now fishing farther offshore, but a significant portion of the nets are sinking before drifting ashore or coming ashore on other beaches, or remaining in the ocean in a gyre.

The 10-year span of Merrell's study would tend to affirm at-sea survival time for floating netting generally of <10 years. The longest float time estimates for recovered netting is 2 years (Tinney 1983). A plastic packing bag found by Merrell (1984) was 4 years old. DeGange estimated a trip of over 100 km in 30 days for a 3,500 m net in the North Pacific, or roughly 3.3 km/day, suggesting long drift times in the open Pacific.

Four natural types of removal from the sea have been discussed. Beach deposition is the only well-documented mechanism. There seems to be no significant deposition on rocky beaches, some on pebbled beaches, and the most on sandy beaches. Deposition increases during winter storms over the normal rate of deposition in the Bering Sea (Merrell 1980) and in the Mediterranean (Shiber 1982).

After deposition, the debris is subject to burial, wind transport to vegetation, gnawing by rats, and resuspension. Dixon and Cooke (1977) found 6% of the material reexposed by storms after burial. To these processes are added the environmental and microbial decay presented below. Based on my beach survey, it appears that a virtually complete elimination of debris is possible in certain circumstances.

The second mechanism is sinking. For netting, with accumulation of fish and other species caught in the net, snagging on the bottom, and the release of floats, the netting may sink at some point. The netting may be removed effectively at this point, or it may start to interact with benthic communities of crabs, lobsters, and other organisms. Considerable debris has been found in benthic surveys of the Bering Sea. Debris was incidental to the biota collected, but in the better sampling series of 1976, Feder (1978) found that 41% of the trawls contained debris. Twenty-three of 43 items were plastic in a category including synthetic rope and twine, plastic objects, and fishing gear categories. Also in 1976, Jewett (1976) found 57% of benthic trawls contained human-made debris. This included large numbers of metal items. This indicates sinking is also a significant mechanism in the removal of debris, although one must question whether this is truly a removal.

A third process is environmental degradation, by the ultraviolet portion of sunlight, through photooxidation, erosion by sand abrasion, molecular breakdown by heat and aging, and fragmentation by wave action. The much lower incidence of reported debris entanglement in tropical latitudes may be due to this photooxidation mechanism. More brittle plastics appear to break down rather quickly in light and heat. Dixon and Dixon (1981) showed that older plastic containers (over 4 years) on beaches were disproportionately fragmented, indicating these processes together occur within 4 years of discard. He suggests photooxidation generally embrittles plastics within 2 years of discard, and that rates of decay for plastic, glass, and paperboard containers are essentially the same. More flexible netting and synthetic twine are not nearly as vulnerable to these processes, and Wehle and Coleman (1983) suggest some plastics may remain on beaches for 5 to 50 years.

The fourth mechanism is microbial action. Although this is mentioned in various papers, it is not enumerated or quantified.

The fifth mechanism, not one of volume but of great potential for research purposes, is regurgitation of debris on land by seabirds.

Based on observations of rapid declines in beach deposition, it appears there is generally a high rate of removal of debris by natural mechanisms. As noted above, 100% elimination is possible for particular areas. On the other hand, for the small pelagic pellets, because of relatively slow rates of degradation at sea, there may be an opposite net effect, that is, a cumulative increase with no equilibrium point, for this one type of debris (Morris 1980b).

The only human removal mechanism now in effect is beach clearing. Merrell (1984) noted trawl floats and inflatable crab pot buoys are prized by collectors, and Dixon (1978) reported on a large annual municipal cleanup in Britain. Although trawl fisheries bring up debris in almost every set in the North Pacific (Branson pers. commun.), it is not retained at this time. The overall volume of debris removed by humans is insignificant, though important for the areas cleared.

INTERACTIONS

An analysis of interactions of marine organisms with debris shows three distinct behavior types. Some involvement with debris is entirely accidental. The object is simply not perceived. The animal gets caught in a net, line, or transparent plastic object which it simply does not see.

Other encounters are indiscriminate. This is particularly true of the ingestion of debris by birds and turtles, and its use as nesting material by birds. The animal sees the object, but cannot distinguish it from an appropriate, natural object. Among birds in particular, this type of behavior varies from species to species, and thus the impact of debris varies as well. Scavenging birds will tend to interact more with debris, whereas "picky" species will not. Thus species which benefit in other ways from flexibility in adaptation to humans will suffer more from the detrimental effects of debris by entanglement than species which are more discriminating and less adaptable to humans otherwise.

Third, some incidents must be categorized specifically as deliberate. Young pinnipeds, with their natural curiosity, deliberately seek out objects with which to interact and in cases of debris come in contact with very differing objects. Indeed, the novelty and variety of the objects may be part of their attraction. In these cases, the type and distribution of debris will have much less effect on the overall rate of interaction and impact of debris on these species.

EFFECTS

Birds

Birds are affected by four types of debris: Particles which are eaten; trash and net fragments with openings in which their head, feet, and wings are caught; lengths of monofilament and string which wrap around wings, beaks, and feet; and large pieces of netting in which they drown immediately.

Rothstein (1973) drew attention to the existence of significant numbers of raw plastic pellets and broken pieces in Leach's petrel stomachs collected in 1962. At least 74% of Laysan albatross carcasses examined in 1966 has plastic in their stomachs or gizzards. The young birds had apparently been fed the pieces by their parents after pick up at sea. Kenyon and Kridler (1969) also observed that the albatross carcasses were the source of abundant plastic litter on Laysan Island, where the tide could not have deposited it. Although the overall amount of mortality was not significant at this large colony, Kenyon and Kridler hypothesized that the young nestlings cannot regurgitate the bulky indigestible pieces along with the usual squid beak castings. He found two pieces of regurgitated plastic sandwich bags. Of the 243 plastic items found in the carcasses, only 1 piece of this baggie material was found; container caps, toys, and broken pieces of plastic made up the rest.

Obviously, such ingestion has been occurring now for at least 22 years, and more likely for as long as plastic has been manufactured. As of 1983, 15% of the 280 species of seabirds are known to have eaten plastic (Wehle and Coleman 1983). This now appears to be a widespread problem of the feeding ecology of seabirds; species in the North and South Pacific, North and South Atlantic, and the subantarctic have been found with plastic in their stomachs.

Ingestion probably affects birds (and other organisms) in four ways: blockage of passages, ulcerations through constant friction, toxic accumulation from the plasticizers, and decreased appetite. Energy resources may not be available for the demands of the reproductive season if the bird's crop is full of plastic and it feels "full." Ingestion seems to affect species differently, depending on their natural capacity for regurgitation and other factors. If the bird is a scavenging species capable of regurgitating, such as gulls and terns, it seems to be able to clear its stomach (and gizzard) of accumulated debris. Elastic thread and many other types of particles are found in regurgitations at gull roosts (Parslow and Jefferies 1972).

If the bird cannot regurgitate, then the debris stays in the birds, adding to the stress and possible death. Puffins, which usually eat only living fish and macrozooplankton, were found to have eaten elastic thread. In the gizzard, the elastic thread balls up, forming a knot 1 cm across in one bird, and blocking the gizzard exit in another. Four of six puffins collected in Great Britain outside the breeding season had elastic thread in their gizzards. Hypothetical reasons for the ingestion of the elastic threads were mistaken identity as pipefish, or ingestion during play. None of three puffins collected during the breeding season from colonies had ingested elastic thread. This species is known to travel considerable distances over the North Sea, wintering out of sight of land, and Parslow and Jefferies (1972) suggest the presence of thread just in nonbreeding birds indicates that this material is widespread in the North Sea. On the other hand, over 100 guillemots and razorbills which frequently pick and play with small floating objects, and also auks, collected in the same area had no elastic in the gizzards.

Birds also become entangled in simple openings in trash, for instance, six-pack holders, and styrofoam cups (Evans 1970). When they dive for an object in the water, the plastic becomes jammed into the head or beak, and the bird starves. A royal tern in Puerto Rico had its lower jaw impaled even in a rigid plastic cup, but a common tern chick in New York was able to free itself from a six-pack holder in which it would have been stuck if it had been older and larger (Gochfeld 1973).

Entanglement in line begins with the earliest known reference to entanglement (Jacobsen 1947). Today the main problem is monofilament fishing line. Common terns and black skimmers from New York colonies (Gochfeld 1973), brown pelicans in California (Gress and Anderson 1983), and the masked booby in Hawaii (Conant 1984), are some examples. A black-crowned night heron was rescued from a tree on the New York coast, to which it had become stuck by its dragging fishing line (Simon 1984). There is little quantification of this impact, though it seems significant only for the pelican, an endangered species. Puncture of the pelican pouch by hooks at the end of the line is also a hazard.

The most serious impact on birds is most likely drowning in ghost nets. High seas drift gill nets with the floats intact are right at the surface, and the birds see the concentration of fish but not the netting. Entanglement is almost always immediate and fatal. Based on data from incidental take by the same process and gear, birds are caught to a depth of several meters, and diving birds such as murres are caught at the greater depths in the nets, and birds including shearwaters and alcids are caught in the top layers. Diving birds comprise approximately 60 to 80% of the seabirds caught in actively used gill nets and may also comprise that proportion of birds caught in ghost nets as well. The presence of other species is thought to depend on distance from shore, time of year, proximity of breeding colonies, type of fish in the area, and mesh size.

Fish

Fish also suffer from ingestion of particles and netting. Although most important commercially, and very important ecologically, impact on fish is the least researched and documented area.

The small plastic pellets have been found in the stomachs of eight species of fish off southern New England (Carpenter 1972b). Kartar et al. (1973) also showed that bottom-dwelling fish in the Severn Estuary, England have debris in their stomachs. One dogfish was caught off Norway with an elastic band around its neck, similar to those eaten by puffins in the North Sea (Parslow and Jefferies 1972). Fish in the Danube have also been caught with debris around their bodies. These incidents do not appear to be significant in harm or mortality.

Manta rays, another commercially fished species, have been documented to be entangled in lost single strands of monofilament lines. The lines wrap tighter and tighter around the wings as the ray swims through the water, and slice through the 20.3 to 25.4 cm (8 to 10 in.) thick, fibrous cartilage. Monofilament is known to have nearly severed these 3- to 4.6-m (10- to 15- ft) wings (Waterman pers. commun.).

An unknown and possible huge mortality up to twice the size of bird loss may be occurring from ghost nets. Nets washed ashore typically have numerous fish carcasses, and one abandoned gill net was 3,500 m long. Less than half (1,500 m) of the estimated total which was pulled aboard contained over 200 chum and silver salmon, and other marine life including 99 seabirds.

Salmon returning to Alaska have crosshatch markings on their sides, indicating problems with netting. Concern has been expressed by the industry about damage to this fishery from incidental catch, and such concerns would also be applicable to the free-floating abandoned gill nets.

Marine Mammals

Marine mammals, although not the most severely affected group as a whole, are the most well documented and involve the most critically endangered species.

Marine mammals die from debris entanglement in essentially three different ways. If the fragments are large (more than about 4.5 kg (10 lb) for the northern fur seal) the animal drowns. Medium fragments (2 to 4.5 kg (4.5 go 10 lb) for northern fur seals) lead to exhaustion, depletion, and starvation due to increased drag. The effort to swim, breathe, and catch food becomes too much for the energy level of the animal (Feldkamp 1983). One unusually large piece removed from a live northern fur seal in

1982 measured 50 m unraveled. Small fragments, including most of the simple trash, kill slowly over months as the animal grows into the loop. Fur, skin, blubber, muscle, and eventually vital organs are constricted or cut through.

In the most dramatic instance of entanglement, 11 of the 26 Hawaiian monk seal pups born in 1983 on one of the few breeding islands either were entangled in netting or playing among netting and debris in the water. Four pups of this critically endangered species were caught in 1983 in netting which snagged on coral, and would have drowned with the next tide had they not been cut out by scientists (Tinney 1983).

Debris entanglement is estimated to cause 50,000 to 90,000 deaths per year in the northern fur seal. The population in 1983 was dropping on the main rookery in Alaska at about 8% per year. At least 50,000 deaths are thought to be due to entanglement; the other 40,000 deaths possible entanglement or possibly some unknown factor such as disease (Fowler 1983). The proportion of entanglement from packing bands rose quickly from 5% in 1970 to 38% in 1973.

Cape fur seals have been documented to be entangled, primarily in plastic, the largest component being packing bands, and also in wire, leather, and rubber rings. These animals were nearly all male (Shaughnessy 1980).

The southern sea lion, Otaria flavescens, (primarily males) has also been documented to be entangled on the Argentine coast, again primarily in packing bands (Ramirez 1984). Cardenas and Cattan (1984) report on entanglement of the Juan Fernandez fur seal, Arctocephalus phillippi, in Chile, again mostly in packing bands.

The endangered West Indian manatee becomes entangled with crab pot lines. One was found with plastic sheeting or bags in the stomach (Wehle and Coleman 1983).

A minke whale was seen ingesting plastic while feeding on the garbage of a commercial fishing ship. The pygmy sperm whale, rough-toothed dolphin, and Cuvier's beaked whale are also known to have ingested debris (Wehle and Coleman 1983).

Sea Turtles

Sea turtles mistake floating plastic bags for jellyfish. Upon being swallowed, the bag does not pass through the turtle and kills it through intestinal blockage. Four of the seven marine turtle species have been found to have ingested plastic (Wehle and Coleman 1983). Ingestion of plastics has been documented in leatherbacks from New York, New Jersey, French Guiana, South Africa, and France; in green turtles from Japanese, Central American, and Australian coastal waters, and in the South China Sea; in hawksbills from the Caribbean coast of Costa Rica; and in olive ridley turtles from the western coast of Mexico. A sea turtle was also seen swimming in the Mediterrean wrapped in a large plastic sheet (Morris 1980a, 1980b).

In addition, young sea turtles which are supposed to feed on small crustaceans crawling on sargassum rafts, now bite styrofoam packing pellets and tar balls (Pace 1984).

Land Mammals

The Spitzbergen reindeer, a small hardy reindeer of the northern island of Spitzbergen, Norway, often becomes entangled in the masses of netting washed ashore on the island (Tressault pers. commun.). A reindeer on Atka Island, Alaska, was also reported entangled in a fishing net (Beach et al. 1976).

Humans

It is thought that some loss of human life during storms in the Bering Sea may be due to loss of power or maneuvering ability from fouling of propellers, shafts, and intakes. Some loss results from ships becoming entangled in their own gear, and some from floating fragments and trash.

Nets caught on obstacles such as rocks, offshore oil structures, and pipelines are a danger to divers and repair workers. Scuba divers are familiar with ghost nets and these are thought to be responsible for some double drownings. Sunken nets are a formidable obstacle and recognized danger to research and military submarines; near fatal encounters have been reported (Evans 1970). Some catalogues of obstacles and wrecks exist to help avoid these areas.

Navigational Hazard

As discussed briefly above, debris is a cause of ship disablement. Most ships carry a scuba diver to free the ship or debris. The impact of the debris varies greatly with the size of the ship; large propellers can chop through small lines easily, but a fragment from a container can easily clog the intake of a small pleasure boat.

Commercial Loss

The most direct and probably largest commercial loss is in the commercial fishing industry. First, the ghost net targets the fishery for which the net mesh and fishing technique were designed. Thus a discarded squid net would be most effective at catching squid, and crab pots keep catching crabs. Secondly, other incidentally taken commercial species, such as salmon, would be lost proportionally with the amount of discard. Third, the netting will take additional resources as it moves (such as sinking) into different areas. Sunken gill nets are thought to entrap lobsters and crabs, and would affect such species as the king crab.

When a ship is disabled, it must pay the mechanical repair costs, including that of disentangling the propellers, added to the lost fishing line, and each lost piece of netting must be replaced at full price.

Other industries, such as cargo shipping and recreational boating are incurring costs in repair of damage caused by debris fouling. Governments also must pay to repair the same type of damage on Navy ships and for the

Coast Guard to rescue ships under dangerous conditions when disabled by debris.

Commercial, subsistence, and recreational use industries involving seabirds are also affected by "ghost fishing." Slender-billed shearwaters, sooty terns, eiders, thick-billed murres, common puffins, and at least 20 to 30 other species are harvested commercially for meat, eggs, and stomach oil. Several of these are species which suffer the highest mortality from netting (Cline et al. 1979).

Guano production of South American and African marine birds although most likely not affected by debris netting at this time, may be susceptible since significant expansion in fisheries is expected in some nearby areas.

Subsistence use of birds by natives in Canada, Alaska, and elsewhere is an important part of their diet. The Faroese take puffin and murres, and Eskimos and Indians on the Arctic coast of Alaska and the Northwest Territories have traditionally taken marine birds and eggs in an annual spring hunt. The more isolated the community is, such as Banks Harbor, Holman Island, Pint Hope, and Point Barrow, Diomeide Island, the greater the importance this element is in diet and culture (Cline et al. 1979).

Recreational activity related to marine birds is an increasing industry for certain areas as well. The small isolated St. Paul and St. George Islands Aleut communities take in hundreds of thousands of dollars each year from birdwatchers (in 1975, $160,000), one of the only commercial sources of income. Companies in almost all North American coastal states and provinces of both coasts have boat or airplane excursions to marine bird viewing areas offshore; and Alaska and Washington State Governments and private organizations have ferries or excursions to seabird colonies (Cline et al. 1979).

Shore communities and resort areas are incurring costs to clean beaches. It is unknown what portion of the litter is sea-deposited, but it is known that large-scale, thorough clean up of almost exclusively sea debris on county and statewide bases requires funding for organization and trash disposal.

Some comment has been made that sharks attracted to entangled fish and corpses of marine mammals have made bathing beaches dangerous and may in some cases force the closing of these areas, resulting in a loss to the local dependent business.

Apart from these economic costs is the aesthetic and cultural costs. This includes beaches and the open sea. Not only is this "cost" often paid by those not responsible for the debris, but it lowers everyone's benefits and expectations for benefits in the future. Although we have become somewhat used to seeing spoiled beaches, this cost is not necessary, and we could raise the standards back to the pleasure of the uncluttered beaches of a century ago.

A final cost is the loss of feedstock to the plastics industry. The cost of fishing and netting to produce plastic raw materials could be avoided by retention and recycling of already manufactured netting.

Commercial Benefits

Debris from discard may be perceived as an economic advantage to the plastic industry through an increased demand for netting when its tearing, repair, and loss bears no cost for disposal of used netting.

The killing of marine mammals by debris may also be perceived as a beneficial result. By removing a competitor for certain species of fish, the availability of those species would be increased, though the catch of target species by the discarded netting would be increased simultaneously.

A small souvenir trade in glass floats has also developed. A single float approximately 4 in. in diameter now sells for about $10 apiece.

Ecological Impacts

Apart from impacts on single species, several ecological impacts have been noted, but there has been no thorough study.

Plastic serves as an additional substrate for marine organisms. Plastic in the Atlantic supports a limited number of species also found on sargassum and some not found on the seaweed. There was a clear dominance of one bryozoan, *Elletra tenella*, which is not found on sargassum, over other bryozoans which normally dominate the available seaweed substrate in that area. *Elletra tenella*'s large success off the Atlantic coast of Florida is thought to be due to the large amounts of plastic debris in that area (Winston 1982). Higher up the scale, tube worms are using the small raw plastic pellets to build their tubes.

Secondary food uptake of plastic pellets has been noted from the South Atlantic and South Pacific. Fish that ate pellets in Ecuadorean ports were taken by blue-footed boobies in the Galapagos Islands and by short-eared owls. A broad-billed prion and its ingested pellets have been found in the stomach of a South Polar skua in the South Atlantic (Wehle and Coleman 1983).

Seven endangered species are specifically vulnerable to debris entanglement. The Hawaiian monk seal, four species of sea turtles, the brown pelican, and West Indian manatee have died, in descending degree, due to entanglement.

Military Impacts

Evans (1970) pointed out the danger to Navy submersibles from ghost nets nearly 15 years ago. Since then the interaction of submarines with actively used fishing nets has grown to a rate of several per year around the British Isles. The disability of either the fishing vessel or the submarine or both appears to have resulted. Although technically an "incidental take" at the first moment, the encounters can be expected to lead inevitably to tearing and debris in the course of the entanglement.

CONCLUSIONS

Entangling debris in general and plastic in particular appear to have been in the marine environment for at least 22 years and probably since the beginning of large-scale plastic manufacturing. In some form, such as pellets, it is a ubiquitous, worldwide pollutant, and in other forms, such as netting and trash, appears to be a large problem in areas of heavy fishing and shipping. Natural removal mechanisms have a significant annual impact on decreasing amounts.

Up to one hundred thousand marine mammals and possibly more die each year. Half or more of the individuals of certain marine reptile species are affected by the plastic litter, and beachcombing land mammals become snarled in nets and die. Loss of human life may be occurring from disabling ships, and sunken nets are a hazard to underwater work on structures and deep submersibles. Direct financial loss may be occurring to the fishing and recreational industries.

The debris portion of the entanglement problem may be virtually eliminated in perhaps 10 years by two simple steps: no dumping and retention of debris brought up during sets.

For certain species, areas, and industries, alleviation before 10 years is highly desirable. Two additional actions, clearing beaches and retrieving sighted debris, will be effective in reducing the problem quickly for critical areas in about 2 years.

Research funds would seem to be best spent equally on producing information directly related to the motivation of fishers, and on monitoring the impact on endangered species to identify areas of critical action.

The plastic itself may be shredded and recycled through melting and respinning. Burning produces highly toxic, undesirable and unmanageable chemical fallout. Biodegradable plastic netting is not perceived as feasible by the fishing or plastics industry. Fortunately, attitude and operational changes can ameliorate the vast majority of the problem immediately. Preventive measures should be taken in the last pristine areas, the Antarctic and the southern ocean.

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STUDIES ON FUR SEAL ENTANGLEMENT, 1981-84, ST. PAUL ISLAND, ALASKA

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ABSTRACT

The incidence of northern fur seals entangled in debris has been monitored during the commercial harvest of subadult male seals on St. Paul Island, Alaska since the late 1960's. In 1981, more intensive studies were initiated on the types of entangling debris, the mode of entanglement, the condition of the entangled seals, and the frequency of occurrence by age and sex of seals. Beach surveys were also conducted to document the occurrence and accumulation of net fragments, plastic packing bands, strings, and ropes. The majority of the entangled fur seals examined during the harvest were entangled in large mesh (>20 cm) trawl net fragments. Plastic packing bands were the next most frequently occurring entangling debris. Fur seals were less frequently observed in a variety of items such as ropes, strings, rubber bands, plastic rings, and a metal headlight ring. The seals entangled in net fragments were primarily entangled around their neck in mesh loops rather than in tears or holes in the webbing. Most of the entangled seals did not have lacerations from the debris. Observations were also made on seals which did not have entangling debris but had scars and wounds indicative of a prior entanglement. Entangled fur seals tagged and released in 1983 were sighted in 1984 indicating the seals can survive at least 1 year with the debris intact. Some of these tagged seals had lost the debris and others still had deep wounds.

INTRODUCTION

The entanglements of northern fur seal, Callorhinus ursinus, in debris were first reported on the Pribilof Islands in the 1930's. These early reports were primarily of seals entangled in rubber bands cut from inner tubes (Scheffer 1950). Subsequent observations of entangled seals were noted frequently through the early 1960's. In the late 1960's concerns over an apparent increase in the number of fur seals observed entangled in net fragments during the commercial harvest resulted in a North Pacific Fur Seal Commission (NPFSC) recommendation that member countries should make efforts to document the incidence of entanglement and attempt to identify and record the types and origin of fishing gear responsible for the problem

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

(NPFSC 1967). Fur seal managers in the United States have monitored the incidence of entangled seals observed during the harvest since 1969 (Fiscus and Kozloff 1972; Scordino and Fisher 1983). Monitoring studies were expanded in 1981 to include more detailed information on the nature and extent of fur seal entanglement.

This paper presents preliminary results of current investigations on fur seal entanglement in 1981-84. The studies were primarily on entangled subadult males observed during the commercial harvest. Although surveys were conducted in the breeding and the haul-out areas, the information presented on the types of debris and the condition of the animals is solely from the entangled seals that were rounded up for the harvest. Tabulations of the entanglement data and the details of the data collection methods are included in the background papers which have been submitted to the Standing Scientific Committee of the North Pacific Fur Seal Commission (Scordino and Fisher 1983; Scordino et al. 1984; Scordino et al.[1]).

METHODS

In 1981 debris from entangled fur seals taken in the harvest was collected and described. Studies were expanded in 1982 to include information on gross pathology and age-weight-length information as described in Scordino and Fisher (1983). The skins from the entangled seals, as well as other skins having characteristic scars or bruises in the neck area from a prior entanglement, were closely examined.

In 1983 and 1984, studies were further expanded and included the participation of Japanese scientists. Entangled fur seals appearing during the harvest were restrained, examined, tagged, and released with the debris intact as described in Scordino et al. (1984). The entangling debris was examined and sampled when possible, and the animal's gross pathology was described. Seals without debris but bearing the characteristic scars or cuts indicative of a previous entanglement were included in the harvest and closely examined. The skins from these "scarred seals" were reexamined in the processing plant after the blubber was removed. Efforts were made to resight the tagged entangled seals and to survey breeding areas to determine the entanglement rate in breeding males and females. Surveys for debris on selected beaches were also conducted to document the occurrence and accumulation of net fragments, plastic packing bands, strings, and ropes.

RESULTS AND DISCUSSION

Incidence of Entanglement

A total of 403 entangled seals were observed during the harvest in 1981-84 which represents an average of 0.42% of the number of seals harvested. This average is similar to the incidence of entanglement

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[1]Scordino, J. N. Baba, H. Kajimura, and A. Furuta. Fur seal entanglement investigations, St. Paul, Alaska. Manuscr. in prep. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way, NE, Seattle, WA 98115.

observed in earlier years which has averaged about 0.4% (Table 1). It should be noted that the 0.4% is a comparative indicator of the rate of entanglement among harvested seals each year. However, the actual rate of entanglement among subadult males may be lower since there are many more seals included in the entanglement observations that are not harvested. The harvest numbers include only the seals taken and do not include oversized seals that are released and others that escape back to the hauling grounds.

Table 1.--Northern fur seals observed entangled in debris during the harvest on St. Paul Island, 1967-84.

Year	Number of seals harvested	Number of entangled seals				Percent of harvest
		Net	Band	Other	Total	
1967	50,229	--	--	--	75	0.15
1968	46,893	--	--	--	75	0.16
1969	32,819	--	--	--	66	0.20
1970	36,307	71	5	24	101	0.28
1971	27,289	69	35	6	113	0.41
1972	33,173	85	53	6	144	0.43
1973	28,482	82	54	1	137	0.48
1974	33,027	90	100	--	190	0.58
1975	29,148	105	101	--	206	0.71
1976	23,096	50	47	--	97	0.42
1977	28,444	45	54	--	99	0.35
1978	24,885	75	40	--	115	0.46
1979	25,762	63	34	7	104	0.40
1980	24,327	83	36	--	119	0.49
1981	23,928	68	20	14	102	0.43
1982	24,828	62	26	14	102	0.41
1983	25,768	79	18	15	112	0.43
1984	22,066	50	20	17	87	0.39

Surveys of the breeding areas in June through August of 1982-84 resulted in few sightings of entangled seals. The incidence of entanglement among adult males and females is considerably less than that observed among subadult males taken in the harvest. The incidence of entangled females averaged <0.04% of the female seals observed in the breeding areas. The incidence of harem bull (males holding females in their territory) entanglement is rare; only one such animal has been reported in recent years.

Entangling Debris

A variety of items have been found on subadult male fur seals (Table 2). Most of the items float, thus it is likely that the seals encounter them on the water surface. A notable exception is a metal headlight ring found on the neck of a seal in 1983 which was probably picked up off the bottom nearshore. The predominant debris found on fur seals in 1981-84 was

Table 2.--Types of entangling debris observed on fur seals during the harvest on St. Paul, 1981-84.

Type of debris	Number of seals 1981	1982	1983	1984	Total
Net fragment, mesh size over 20 cm	45	52	52	37	186
Net fragment, mesh size under 20 cm	4	5	6	3	18
Net fragment, undetermined mesh size	19	5	21	10	55
Monofilament gill net fragment	0	3	2	4	9
Cord used in net construction/repair	3	4	2	2	11
Plastic packing band	20	26	18	20	84
String	5	3	2	4	14
Rope	1	2	2	5	10
Rubber band	3	0	1	0	4
Plastic ring	1	0	1	1	3
Plastic gasket	0	0	2	0	2
Monofilament line	0	1	0	0	1
Plastic six-pack holder	0	1	0	0	1
Plastic packing web	0	0	1	0	1
Plastic object	0	0	0	1	1
Lawn chair material	1	0	0	0	1
Cloth sack band	0	0	1	0	1
Metal headlight ring	0	0	1	0	1
Total	102	102	112	87	403

trawl webbing followed next by plastic packing bands. Infrequently occurring items include ropes, cords, strings, and rubber or plastic bands. The more unique items found on seals were a plastic six-pack holder for canned drinks which was broken and stretched between two of the six holes, a cloth band which is used to seal burlap on synthetic sacks, and a flat 13 cm wide piece of half-moon shaped plastic which had a small hole that was just large enough to go around the seal's lower jaw.

Trawl webbing accounted for 62-72% of the entangling debris. Most of the webbing examined since 1981 has had a stretched mesh size of greater than 20.0 cm with the 23.0 cm mesh occurring most frequently (Table 3). The larger mesh webbing (>20 cm) has a greater entanglement potential than the smaller mesh since each mesh loop in the larger webbing can become entangled over a seal's head; whereas smaller mesh webbing would require holes or tears of appropriate size to entangle a seal. Most seals entangled in trawl webbing were caught in the mesh loops rather than in holes. The high occurrence of larger mesh webbing on seals contrasts with the composition of webbing washed up on the beaches of St. Paul, St. George, and Amchitka Islands. Fowler et al. (1985) reported over 70% of the net fragments on these beaches were of smaller mesh sizes (<20 cm). If the debris on the beaches of these three islands is representative of the debris at sea, then most of the webbing at sea (which is of smaller mesh sizes) has low entanglement potential.

Table 3.--Mesh sizes of net fragments (excluding monofilament gill nets) on fur seals observed during the harvest on St. Paul, 1981-84.

Mesh size (cm)	Number of seals				
	1981	1982	1983	1984	Total
7.0	1	--	--	--	1
7.5	--	1	--	--	1
10.0	--	--	1	--	1
11.5	1	--	--	--	1
12.5	1	1	--	--	2
13.5	--	--	--	1	1
14.0	--	--	2	--	2
15.0	1	--	--	1	2
16.5	--	2	2	--	4
18.0	--	1	--	--	1
19.0	--	--	2	1	3
20.5	3	5	--	1	9
21.5	4	5	12	12	33
23.0	31	36	28	12	107
24.0	3	2	6	8	19
25.5	3	2	--	2	7
26.5	--	--	2	1	3
28.0	1	1	1	1	4
29.0	--	1	2	--	3
30.5	--	--	1	--	1
39.5	--	1	--	--	1
Undetermined	19	5	21	10	55
Total	68	[1]63	[2]80	50	261

[1]One oversized seal with two different nets is tallied twice; once as a 16.5-cm mesh and once as a 39.5-cm mesh.
[2]One oversized seal with two different nets is tallied twice; once as a 14.0-cm mesh and once as a 16.5-cm mesh.

Note: This table does not include nine seals observed entangled in monofilament gill net fragments as follows:

1982 - Three seals were entangled in 11.5 cm mesh gill nets.

1983 - Two seals were entangled in gill net; one in 11.0 cm mesh and one in 11.5 cm mesh.

1984 - Four seals were entangled in gill net; one in 11.0 cm mesh, one in 12.0 cm mesh, and two in undetermined mesh size.

Plastic packing bands were the next most frequently occurring debris entangled on seals. The incidence of plastic packing bands ranged from 16 to 26% of the debris entangled on seals. This greatly contrasts with the period 1974-77, when the bands accounted for 48-55% of the debris entangled on seals, with the number of bands exceeding the number of net fragments in both 1974 and 1977. Most plastic bands entangled on seals were hot-sealed into loops and the remainder were tied into a loop with a knot. The loops had a circumference of 38-96 cm, and the bands varied in width from 0.3 to 1.6 cm. The yellow plastic packing band occurred most frequently followed by blue, white, green, black, and pink. It is unknown if fur seals are attracted to particular colors or if the incidence of some colors is related to occurrence of the debris at sea.

United States and Japanese gear experts examining the nets removed from seals in 1982 and 1983 determined that all of the net fragments (other than gill nets) were polyethylene trawl nets. The majority of the net fragments (67) were from bottom trawls; 9% were midwater trawl webbing, and 24% could not be identified to trawl gear type. The larger mesh sizes commonly found entangled on seals were from the belly and wing areas of the trawl nets.

The largest piece of debris found on a seal was a piece of trawl webbing weighing 6.75 kg. However, the most frequently occurring debris on seals were small pieces of trawl webbing weighing <150 g. The smaller pieces of debris (weighing <150 g) including the small pieces of webbing, plastic bands, and other debris account for over 60% of the debris found on seals. The high incidence of small debris entanglements may be due to the seals "playing" with smaller pieces of debris, as they do with kelp, and becoming entangled in the process. Observations of seals avoiding contact with actively fished high seas gill nets (Jones 1982) indicate that seals are probably aware of larger pieces of webbing and therefore do not haphazardly become entangled. It is likely that entanglement is probably due to the seal's investigative nature rather than seals "blindly" running into debris at sea.

Effects of the Debris

Entangling debris can detrimentally affect a seal if the debris is constricting, causes lacerations, or impairs swimming or feeding abilities. Most entangled seals have the debris around their neck, but a few had webbing around their flippers that might directly impair swimming. Also the increased drag caused by larger net fragments as described by Feldkamp (1984) may indirectly impair swimming and feeding ability. In some instances the debris may directly impair feeding. An example of this is three seals observed in 1983 that had webbing around their head and mouth that would impair food passage.

Most (64%) of the entangled seals observed in 1982-84 did not have cuts or wounds. This may be because the animals became entangled recently, or it could be that it takes a long time for cuts to develop. The type and quantity of debris appear to affect the progression of skin trauma. The animals with 360° wounds were most frequently entangled in small single-strand pieces of debris. Conversely, there was only one seal with an open wound among those with more than eight mesh loops of webbing around their neck. The thin pieces of debris, such as the monofilament gill nets and strings (when tightly bound on the neck), appear to cut the skin more rapidly since all seals observed with this debris had open wounds.

The incidence of wounds on entangled seals increased with increasing age. Open wounds were observed on 24% of the entangled 2-year olds, 30% of the entangled 3-year olds, 50% of the entangled 4-year olds, and 82% of the entangled seals 5 years and older. This increased incidence of wounds with age suggests the possibility that seals can survive entanglement for long periods of time as the debris slowly cuts into the skin as the seal grows. Supporting this is the observation of one seal, entangled in webbing and without wounds in 1983, which as resighted a year later with debris intact, still without wounds. However, other observations (Table 4), such as five seals with debris and without wounds in 1983 and subsequently resighted in 1984 with wounds, might suggest the debris cuts through the skin in a relatively short period of time. Unfortunately, the ages of these tagged seals were not determined (since they were released alive), and the possibility of differential growth rates cannot be assessed.

Entanglement Scars on Seals Without Debris

Each year a number of seals are observed without debris but possessing characteristic cuts, bruises, or scars on their necks and shoulders. These marks have been determined to be caused by prior entanglements (Scordino and Fisher 1983). Before 1981 these "scarred seals" were included in the skin processing plant tally of skins with entanglement scars, but they were not tabulated separately from the skins which came from seals that had entangling debris on them when taken. Conversely, some of the skins from entangled seals do not have marks or scars and because of this, they may not have been included in past processing plant tallies. Due to these discrepancies, pre-1981 processing plant tallies could not be used to determine the number of seals having prior entanglement. To obtain information on the numbers of seals that were previously entangled, the studies in 1982-84 emphasized observations on entanglement scarred seals during the harvest and observations of skins in the processing plant. Entanglement scars are not always obvious and sometimes difficult to see on live animals, but are usually apparent in the dermis after the blubber has been removed or when the guard hair has been removed during the finishing process. One example of this is a skin observed in the processing plant that had a monofilament gill net imbedded in the blubber around the neck area, yet no scars nor abnormalities were visible in the hair.

In 1982, 91 (0.37%) of the seals harvested had characteristic scars or bruises in the hair and skin around their necks or shoulders indicative of a prior entanglement. Most scars were not evident on live seals, becoming evident only on the skin during processing: 22% were observed on the animals during the field harvest; 37% were observed on skins in the skin processing plant on St. Paul; and 41% were observed on skins after the guard hair was removed.

Eighty-two (0.32%) of the seals harvested in 1983 and 68 (0.31%) of the seals harvested in 1984 had scars or bruises indicative of a prior entanglement. The 1983 and 1984 figures do not include observations made on the 1982 skins after guard hair removal and therefore may be low. Most

Table 4.--Comparative observations of entangled seals tagged in 1983 and observed in 1984 with debris intact.

Tag No.	1983 Observations	1984 Observations
423	Net green; tight on low neck. 360° deep open wound, 2 cm wide. Mesh entanglement; 21 cm mesh.	Net green; on tight. 360° open wound; 2 cm wide, skin bulging. One mesh loop around neck.
436	Net green; tight but not binding on neck. No wounds. Five mesh loops around neck; 23 cm mesh.	Net green; on neck. Deep cut.
444	Net gray; loose on neck. No wounds. Five mesh loops around neck; 23 cm mesh.	Net gray; on tight. 360° open wound; skin bulging.
464	Rope greenish; tight on neck. 270° open wound; 90° healed over ventrally. Tied into loop via one knot.	One strand of undetermined debris. 360° open wound. Knot ventrally with 3 cm of twine hanging.
466	Net gray; loose on neck. 360° deep open wound; 2-6 cm wide. Two mesh loops around neck; 23 cm mesh.	Net gray; on neck. (No further observations reported.) Net removed by biologists on St. George.
468	Net brownish red; tight on neck. No open wounds. Two mesh loops around neck; 21.5 cm mesh.	String yellowish; on neck. 360° open wound; wide, deep wound.
471	Net gray; tight on neck. No open wounds. Ten mesh loops around neck; 21.5 cm mesh.	Net gray; on tight but not binding. No open wounds.
472	Net gray; tight on neck. No open wounds. Eight mesh loops around neck; 23 cm mesh.	Net gray; on tight. 360° open wound; not deep; but through skin.
480	Net green; very tight on neck. 360° open wound; not deep, but through skin. More than two mesh loops around neck; 24 cm mesh.	Net green; very tight on neck. 180° open wound dorsally; does not appear cut ventrally. Fur scars at gape of mouth suggesting mesh loops may have entangled around mouth.
487	Net green; tight but not binding on neck. No open wounds. Large quantity of net; 16.5 cm mesh. Webbing had whitish repair cords entwined.	Net gray; on neck. 360° open wound; very deep cut, skin bulging. One strand of debris with large knot ventrally.
489	Plastic gasket; tight on neck. 360° open wound; not deep, but through skin.	Plastic gasket; on neck. 360° deep open wound down to muscle. Gasket was cut off and seal released alive. Seal sighted 2 weeks later with healed wound.
497	Net gray; tight on neck. 360° deep open wound. Four strands around neck.	Net yellowish; on neck. Deep cut.

(60%) of the entanglement scars in 1983 and 1984 were observed during the field harvest. Although observations during the harvest of larger males with entanglement scars have been recorded, they are not included in the above totals since these animals, which are longer than the established harvest size limit, are allowed to escape the harvest. Since no efforts were made to examine each of these escaping seals, the number of previously entangled seals on the haul outs may be greater than that reported above.

The occurrence of these entanglement scarred seals clearly indicates that the seals can rid themselves of entangling debris, and that entanglement does not always result in death. Observations of seals without debris, but with open wounds around their neck indicate that seals can rid themselves of debris even after it has cut into the skin. This is further evidenced by observations of skins with prior-entanglement scars that had new skin growth, indicating a prior open wound.

Tagging Studies

Over 150 entangled fur seals (primarily subadult males) were tagged and released with the debris intact in 1983 and 1984. These tagging studies provide new insights not only on the longevity of entangled seals, but also on the incidence of debris loss. Although it was known that some seals rid themselves of entangling debris, as evidenced by observations of past entanglement scars, it was not known how frequently this occurred nor what types of debris were involved. It was assumed that seals entangled in large or trailing pieces of webbing could snag the webbing on rocks and pull themselves out, but it was never thought that seals could rid themselves of tightly bound small pieces of debris such as plastic packing bands.

Of the 95 entangled seals tagged in 1983, 25% were resighted in 1984. This was a much greater return than anticipated. A comparison of this with the tag recovery of unentangled seals under similar conditions (Griben 1979) shows no statistical difference ($P \geq 0.95$) in the returns of entangled seals (A. York pers. commun.). This suggests that the mortality of entangled seals is not significantly different from that of "normal" seals over a 1-year period. It was also assumed when these studies began in 1981 that entangled seals with 360° open wounds would not survive more than a few months (Fowler 1982), but as shown in Table 4, wounded entangled seals can survive at least 1 year with the debris intact. Of the entangled seals resighted with debris intact in 1984, 50% had open wounds when tagged in 1983.

Of the entangled seals tagged in 1983, 18% were resighted without debris (Table 5). Most of these had no open wounds when tagged, and many had no marks or scars visible when resighted. The entangling debris on these seals was: 35% small pieces of webbing, 18% larger pieces of webbing, 18% plastic packing bands, and 29% miscellaneous debris such as strings, rubber bands, gaskets, and other items. It was surprising to find the higher frequency of loss of smaller pieces of webbing, since these pieces are not large enough to get stuck on rocks or other objects to enhance the seal's escape. It is not obvious as to how seals rid themselves of small debris. The plastic bands and the trawl webbing are made of polyethylene and therefore would not break off the seals easily.

Table 5.--Observations of entangled seals tagged in 1983 and subsequently observed without debris.

Tag No.	Date tagged	Observations at time of tagging	Date observed without debris	Notes
403	7/5/83	Net green; tight but not binding on neck. No open wounds. Very small quantity of net. Sighted 7/25/83 with debris intact.	7/28/83	No debris.
411	7/8/83	Band yellow; tight but not binding on low neck. No open wounds.	7/27/84	No debris. No open wounds; slight indentation in skin over left shoulder.
420	7/11/83	Rubber band on head. No open wounds.	8/2/83	No debris. No marks.
425	7/12/83	Band white; loose on neck. 180° open wound. Sighted 8/1/83 with debris intact.	7/11/84	Seal not observed, but one tag was found during harvest drive. As no previously tagged, entangled seals were seen in the harvest; the seal may have lost the debris.
428	7/13/83	Net green; tight but not binding on neck. No open wounds. Small quantity of net.	7/16/83 and 7/6/84	No debris. No marks.
429	7/13/83	Net green; tight but not binding on neck and flipper. No open wounds. Medium amount of net. Sighted 7/25/83 with debris intact.	7/20/84	No debris. No marks.
430	7/13/83	Net green; tight but not binding on neck. No open wounds. Large amount of net. Sighted 7/20/83 with debris intact.	7/2/84	No debris. No marks.
434	7/13/83	Band yellow; tight but not binding on neck. No open wounds.	8/3/83	No debris. Fur mark on neck, 8 cm wide.
438	7/14/83	Net green; on neck and flipper. No open wounds. Large amount of net; 25 mesh loops around neck. Sighted 7/19/83 with debris intact.	7/25/83	No debris.
441	7/15/83	Net gray; loose on neck. No open wounds. Small amount of net.	8/8/83	No debris. No marks.

Table 5.--Continued.

Tag No.	Date tagged	Observations at time of tagging	Date observed without debris	Notes
442	7/15/83	Net gray; very tight on neck. 270° open wound. One mesh loop total. Sighted 7/25/83 with debris intact.	7/5/84	Debris not observed. 360° open wound. Sighted again on 7/19/84; definitely no debris; laceration healed.
476	7/28/83	Plastic packing material; tight on shoulders. No open wound.	7/24/84	No debris. Slight 60° fur mark on right shoulder.
477	7/29/83	String beige; tight on shoulders. 70° open wound on each shoulder. Sighted 8/3/83 with debris intact.	7/6/84	No debris. Obvious fur marks on shoulders; appear to be recently healed.
482	7/29/83	Net gray; loose on neck. No open wounds. Small amount of net.	7/22/84	No debris. Scars present on neck.
493	8/5/83	Rubber gasket; tight on neck. No open wounds.	8/1/84	No debris. Faint scars present.
495	8/5/83	Net gray; loose on neck and flipper. No open wounds. Small amount of net.	6/24/84	No debris.
498	8/5/83	Cloth band white; loose on neck. No open wounds.	7/27/84	No debris. No marks.

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Also it is unlikely that the debris would slip off over the seal's head since it is likely that the debris would move posteriorly to larger parts of the body as the seal swims forward and the posteriorly sloping guard hairs would tend to resist movement of the debris anteriorly towards the head.

CONCLUSIONS

These studies provide basic data on fur seal entanglement and shed new light on the potential impact of entanglement on northern fur seals. Fur seal mortality resulting from entanglement may not be as high as has been assumed (e.g., see Fowler 1982). The tagging and resight data suggest that entangled seals may not experience increased mortality, at least over a 1-year period. Previous assumptions by Fowler (1982) that seriously wounded seals would die in a short period of time are not supported by the tagging data. The likelihood of entangled seals ridding themselves of debris is much higher than previously assumed especially in view of the observations of seals that had rid themselves of various types of debris and the relatively high incidence of entanglement scars on fur seals without debris. These observations and others made during this study, such as the apparent low probability of entanglement in much of the debris at sea, indicate that past analysis and assumptions on the potential impact of entanglement of the fur seal population need to be reevaluated and further investigated.

Further studies on the incidence and effects of entanglement by age and sex are needed. Current studies were essentially limited to the subadult male seals during the harvest and should be expanded to include detailed information on all entangled seals including females occurring on land from June through September. Increased resighting effort is needed to obtain further information on entanglement mortality and loss of debris. Surveys of debris washed up on the beaches of the Pribilof Islands, other areas in the Bering Sea, and in the North Pacific should continue so as to determine the abundance of debris with entanglement potential and the deposition and recyling of such debris.

ACKNOWLEDGMENTS

These studies were conducted in cooperation with the National Marine Mammal Laboratory, National Marine Fisheries Service (NMFS), NOAA and the Far Seas Fisheries Research Laboratory (FSFRL) in Japan. Of special mention are Hiro Kajimura, NMFS, and Kazumoto Yoshida and Norihisa Baba of the FSFRL, who participated in the field studies. Others involved in the field studies included the veterinarians present at the harvest each day: Robert Fisher in 1982; Gerard Beekman in 1983; and Michael Stoskopf in 1984. Special thanks for their cooperation and assistance are extended to the St. Paul Island sealing crew led by Vyacheslav Melovidov and the St. Paul processing plant crew led by Feddie Krukoff and David Albrecht of the Fouke Company in Greenville, South Carolina.

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AN EVALUATION OF THE ROLE OF ENTANGLEMENT IN THE POPULATION DYNAMICS OF NORTHERN FUR SEALS ON THE PRIBILOF ISLANDS

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ABSTRACT

The population of northern fur seal, Callorhinus ursinus, on the Pribilof Islands has been declining since the mid- to late 1970's at the rate of about 4.0-8.0% per year. Previous work has pointed to the possibility that mortality caused by entanglement in fishing debris and plastic packing bands is contributing to this decline. In this earlier work crude estimates of mortality rates were derived, some being based on a comparison of the composition of debris on seals with that on beaches. Evidence that entanglement may be involved in the population decline is seen in the fact that the observed entanglement and the decline correspond in time. At a more detailed level, correlations exist between estimated mortality rates, rates of change for two components of the population, and observed entanglement.

In this paper details concerning these correlations are presented. One of the most important correlations is that observed between the rates of change in estimated numbers of pups born and entanglement observed in the harvest. All of the difference between the expected rate of increase at current population levels and the current rate of decline is accounted for statistically in this correlation when the rates of decline are lagged to account for the mortality and maturation of the parental females. There is a similar correlation for adult territorial males with females, again lagged to account for maturation. Details of the correlation between entanglement rates and the discrepancy between expected and observed early mortality in males are also presented. Based on this correlation none of the extra 15 to 20% mortality currently observed would be expected if entanglement rates were zero. Changes in the index of the survival of animals of the ages taken in the harvests, as based on changes in the age structure of the harvest, correspond in time with observed entanglement rates but are not correlated with them.

Although the contribution of entanglement to the current decline appears significant, a precise estimate of entanglement

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

caused mortality has not been produced. Advances have been made, in this regard, through the analysis of the age structure of entangled animals in the male harvest as compared with the entangled animals.

INTRODUCTION

The population of northern fur seal, Callorhinus ursinus, on the Pribilof Islands, Alaska, has been declining for about the past decade at approximately 4.0-8.0% per year (with a mean of about 6.1%) as determined from the numbers of pups born each year since the mid-1970's (Fig. 1). This decline occurred after the development of extensive commercial fisheries in the late 1960's in areas used by fur seals, so commercial fishing was suggested as a potential causal factor. It was thought that reduced food supplies might explain the decline (U.S. Department of Commerce 1980). However, changes in growth, pup survival, and other characteristics of the seals themselves (i.e., the health of individual animals) were found to be inconsistent with a limited food supply (Fowler 1984b). Diseases, predation, and toxicants have been identified as other possible contributing factors although none of the limited data for these factors have been found to show any significant relationship with the decline.

Northern fur seals on the Pribilof Islands have been observed entangled or caught in debris since at least 1936 (Fiscus and Kozloff 1972). Early observations indicated that seals were entangled in rubber bands, cords, strings, and rawhide. In the early 1960's fishing effort in the North Pacific and Bering Sea increased (Low et al. 1985), as did the use of synthetic nonbiodegradable fibers in fishing nets and packing bands. The entanglement of seals in such materials increased from the mid-1960's to the early 1970's (Fig. 1). Currently (1984-85) about 0.4% of the harvested juvenile males are entangled. This figure includes a few older animals taken specifically because they are entangled. Entanglement rates have been recorded from the harvest consistently since the mid-1960's and, as such, are both close to and serve as good indices of the portion of harvestable-aged males that are entangled. About two-thirds of the pieces of debris found on these animals are fragments of trawl net webbing. Most of the remaining objects are plastic packing bands (Fowler 1982a; Scordino and Fisher 1983).

Entanglement in lost or discarded fishing gear or other debris, as a potential contributor to the decline in fur seals, has been seen as historically associated with the increase in fishing activity and the decline in fur seals (Fig. 1). The general temporal correspondence of these events was the basis for suggesting that entanglement might be the cause of the decline (Fowler 1982a, 1982b). These circumstances alone, however, were insufficient to clearly identify the extent to which entanglement might be contributing to the decline. Early estimates of the mortality rate caused by entanglement were provisional; improvements were needed.

All attempts to estimate entanglement-caused mortality rates have involved making various sets of assumptions for which there are limited data. These exercises, and the associated population modelling (Fowler 1982a, 1982b, 1984a; Swartzman 1984), clearly demonstrated the feasibility

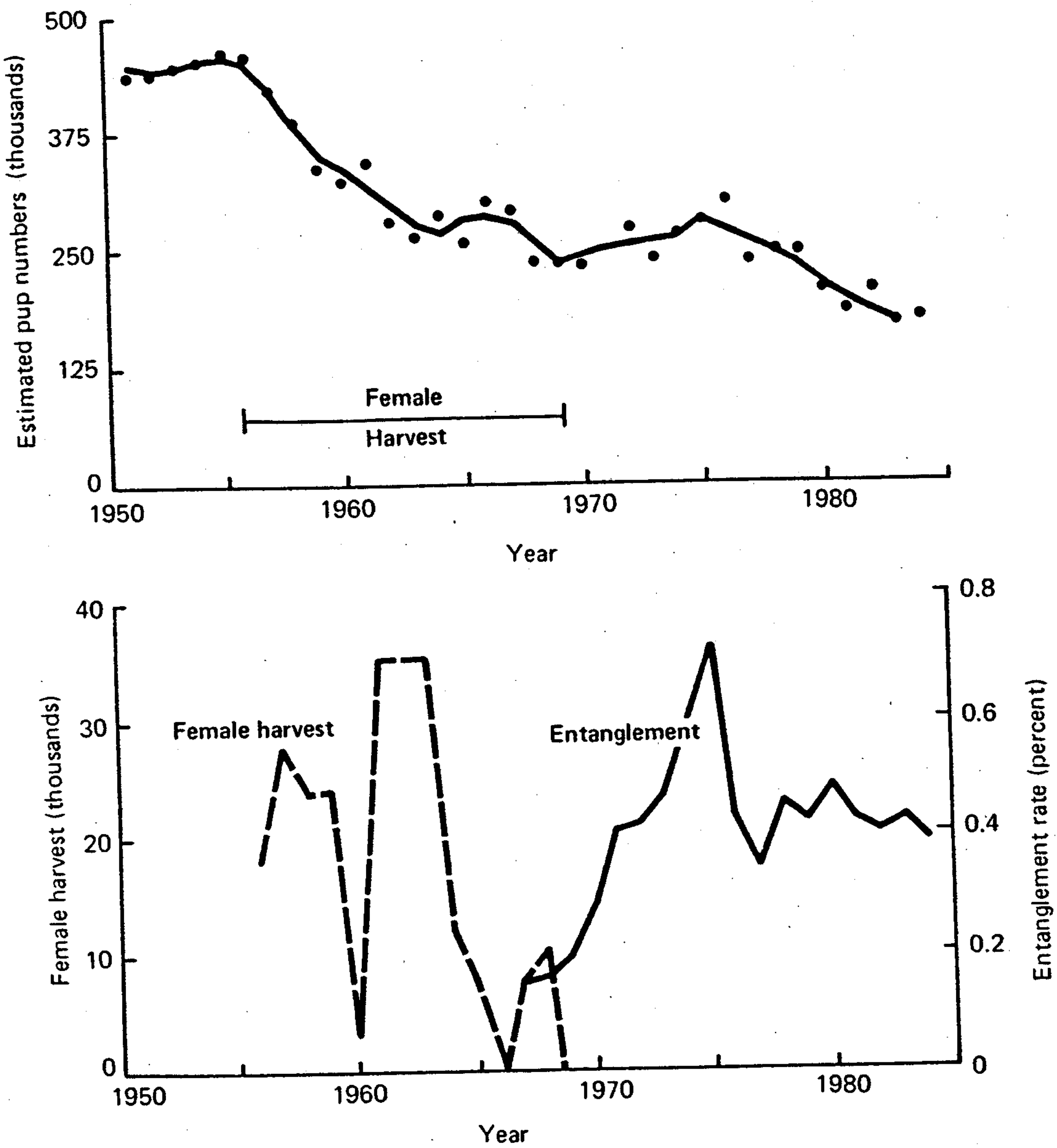

Figure 1.--The estimated number of pups corresponding to the female harvest and observed entanglement for St. Paul Island, Alaska, 1950-84. The dots in the top panel show estimated pup numbers for 1950 to 1984. The solid line represents the running arithmetic mean of 3. The bottom panel shows the female harvest for St. Paul and the entanglement rate observed in the harvest of subadult males.

of entanglement as a cause of the declining fur seal population but made very limited progress toward statistically reliable estimates of the resulting mortality. Increases in the estimated mortality of juvenile males during the first 20 months at sea did not rule out reduced reproduction as a contributing factor in the overall population decline, but helped focus attention on entanglement and other possible sources of mortality such as diseases, toxic substances, and predation.

paper, statistical analyses of the correlations between the
tanglement rates are presented, along with an attempt to
lement-caused mortality of males between the ages of 2 and 3
e structure of entangled animals compared with the
ales taken in the harvest on St. Paul Island. Information
changes in the survival of older males is also presented.

Correlation Between Survival and Entanglement

In choosing among emigration, changes in survival, and changes in reproduction, the three principal possible causes for the current decline, scientists have made special note of the decrease in the survival of subadult males (North Pacific Fur Seal Commission 1982, p. 26). The current decline has been explained by assuming that the survival of females is equivalent (or nearly equivalent) to that estimated for males (Trites 1984). Between 1965 and 1970 the mean estimated survival during the first 20 months at sea for young males was about 41% whereas the current rates (1980-85) are down to nearly 30% (Fowler 1982a).

Observed entanglement rates rose between 1965 and 1970. Prior to 1965, the estimated survival of young males (0- to 2-year olds) at sea was correlated with the survival of pups on land (Lander 1981). Following 1965, however, this correlation no longer existed (Fig. 2; Fowler 1982b). To examine the potential role of entanglement in this unexpected change, tests were conducted to see if the discrepancy between observed survival and that expected from pup survival on land was correlated with observed entanglement rates.

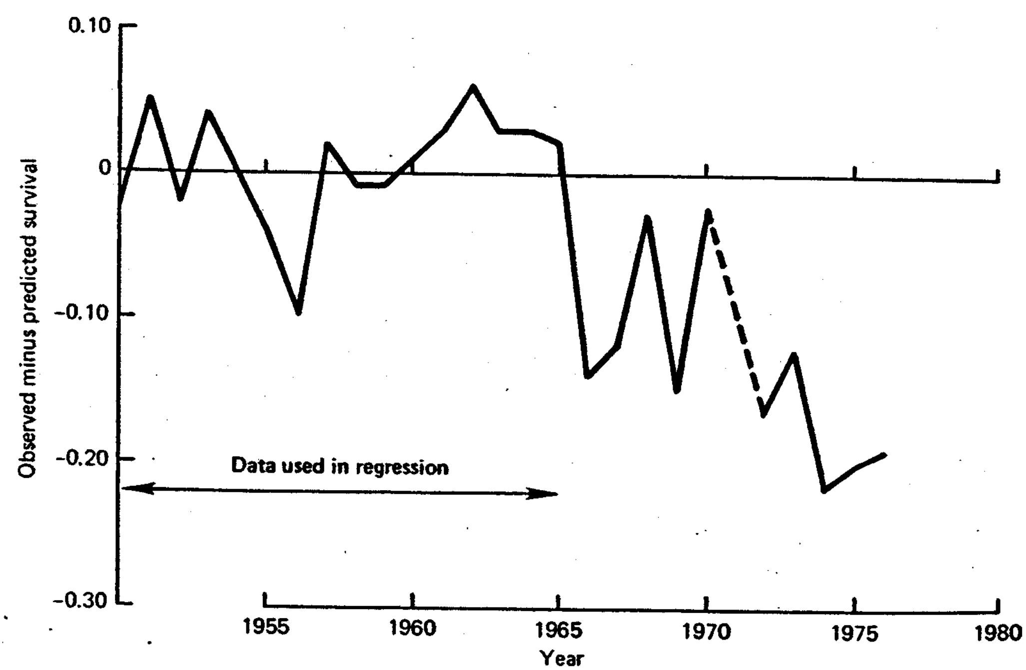

Figure 2.--The discrepancy between predicted and observed survival during the first 20 months at sea for males, based on a correlation between at-sea survival and on-land survival at St. Paul Island from 1950 through 1965 (updated from Fowler 1982b).

First, a simple linear analysis of covariance was conducted to see if estimated survival of young males at sea is correlated with pup survival on land. No significant correlation was found when using all available data from 1950 to the present in spite of a significant correlation for the data from 1950 to 1965. When the observed entanglement rate was introduced as a covariant (assuming zero rates for years earlier than 1967), the resulting multiple regression model was found to represent a significant relationship ($P < 0.05$). These results indicated the need to look more closely at the effect of entanglement in spite of some of the violations of the assumptions involved in linear regression analysis (e.g., that the independent variables exhibit variance).

Another approach was designed to examine specifically the relationship between observed entanglement rates and the unexpected reduction in survival shown by the multiple regression model described above. First, to elucidate any trend that might be hidden by year-to-year variability, the interannual variability of the discrepancy shown in Figure 2 was removed by calculating a running arithmetic mean of three yearly observations. These (means) were then plotted against the rate of entanglement observed in the year of birth of the cohort to which the survival rate applies (Fig. 3).

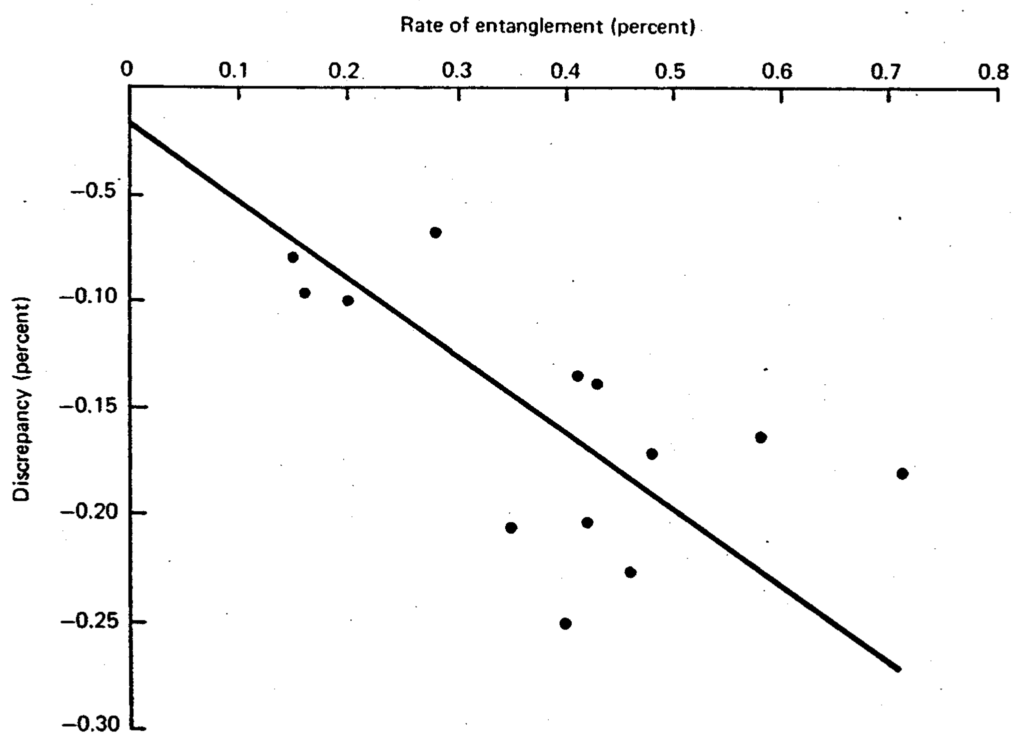

Figure 3.--The correlation between the discrepancy between predicted and observed survival of juvenile male fur seals and entanglement rates 1 year later.

The two variables defined were found to be significantly correlated (Fig. 3) using rank correlation tests ($P < 0.05$). The line shown in Figure 3 was determined by minimizing the sum of the squared error defined as the perpendicular distance between the points and the regression line (Ricker 1973, 1984). This process was used in place of ordinary linear regression since both variables exhibit a nonzero variance. The objective was to find the underlying relationship between the two variables.

The equation for the regression line of Figure 3 is

$$y = -0.016 - 0.360x \qquad (1)$$

where y is the discrepancy defined above and x is the observed entanglement rate for the year after the birth of the year class for which the estimated survival was calculated. From this relationship, if there were no entanglement we would expect almost no difference between the observed survival and that expected from the correlation with pup survival on land. This expectation is consistent with the view that natural survival (survival as affected by factors other than entanglement) is responding in a density-dependent fashion, but overall survival currently includes a significant effect due to entanglement. There is a statistically significant relationship between early survival at sea and the two variables of estimated pup numbers and observed entanglement rates (Fowler 1984b). Neither variable is significantly related to early survival alone.

One potential problem with the approaches taken above involved the introduction of serial correlation in the dependent variable by taking mean over time. Therefore, further analyses were conducted using the raw data (i.e., no 3-year averages) for the discrepancy in Figure 2 as correlated with observed entanglement rates. Again, rank correlation tests found a significant relationship ($P < 0.05$). The intercept of the regression line resulting from ordinary linear regression analysis of the raw data was not found to be significantly different from zero (i.e., not different from a regression equation which would predict zero discrepancy at zero levels of entanglement).

Correlation Between Rate of Change in Pup Numbers and Entanglement

If high mortality of young animals (0- to 3-year olds) is causing the decline in population, and if this mortality is caused by entanglement, a correlation between the rate of change of pup numbers and observed entanglement rates should be observed. This correlation would be expected to involve a time lag to account for the time required by females to reach reproductive maturity (about 6 years, York 1983).

The historical data were examined for such a correlation by removing interannual variability in estimated pup numbers by using the mean of three adjacent data points in place of that of the second year (Fig. 1). The rate of change was then calculated from these means as a simple annual net rate of change (y):

$$y = (N_{t+1} - N_t)/N_t \qquad (2)$$

where N_{t+1} = pup numbers (mean of 3 years) for year t+1 and

N_t = pup numbers (mean of 3 years) for year t.

These rates of change were then plotted against the observed rate of entanglement of subadult males from 6 years earlier (Fig. 4). Rank correlation analysis showed this relationship to be significant ($P < 0.05$). The line shown in Figure 4 resulted from applying the procedure of Ricker (1973, 1984) with the regression equation:

$$y = 0.0760 - 0.2782x \tag{3}$$

where x is the observed entanglement rate 6 years prior to the year of calculated change.

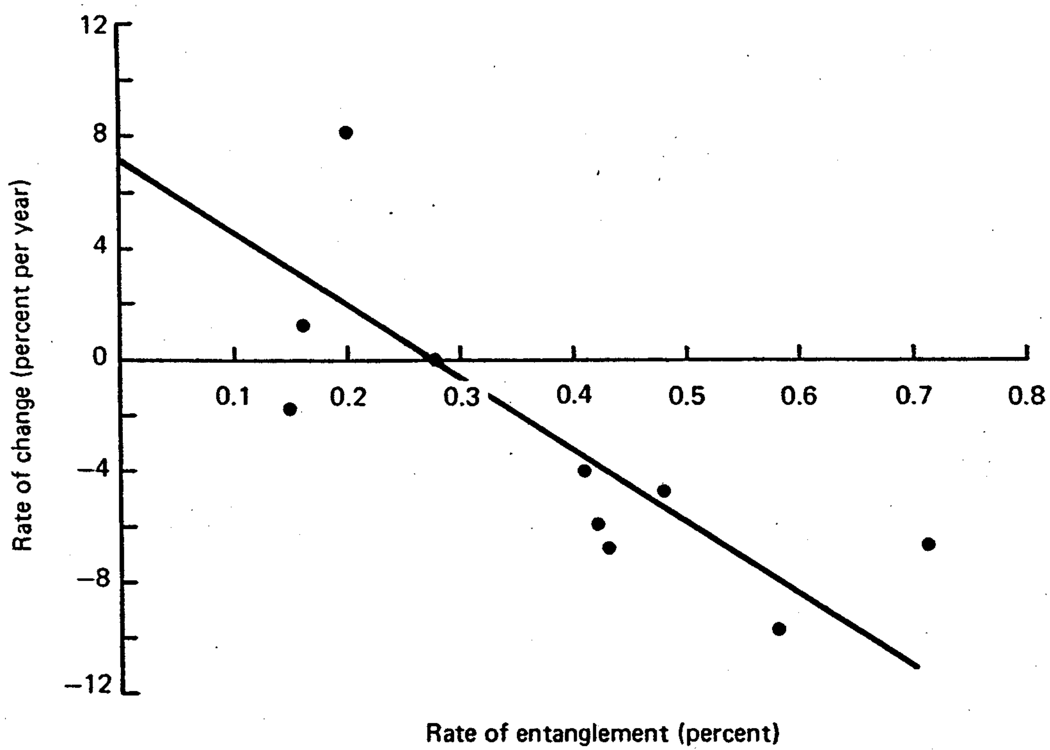

Figure 4.--The correlation between the rate of change in estimated fur seal pup numbers (as determined from a running mean of 3) and observed entanglement rates 6 years earlier.

Although serial correlation of the dependent variable may influence, to some extent, the accuracy and precision of the results of the analyses above, we have identified in Equation (3) a relationship between entanglement and the rate of change in pup numbers on St. Paul Island. Assuming that this relationship can be represented by Equation (3) and that it represents the role of entanglement, an increase in pup numbers at the rate of about 7.6% a year would be expected if the entanglement rate were zero. The current rate of decline of about 6.1% per year corresponds to the approximate 0.5% observed entanglement rate of 6 years ago (obtained as the mean of entanglement rates observed in 1975-77).

As mentioned above, the intercept of the regression line in Figure 4 can be interpreted as a prediction that pup numbers would be increasing at the rate of 7.6% per year if the entanglement rate were zero. This rate is insignificantly different from 7.4% per year, the rate of change observed in the early to mid-1920's when pup numbers were last at currently observed levels. The difference between the current rate and the rate observed in the early 1900's is 13.5% (7.4 + 6.1 = 13.5). In other words, pup numbers are changing at rates 13.5% less than expected for current population levels. The relationship shown in Figure 4 accounts for all of the difference.

Conventional linear analysis, again potentially influenced by serial correlation, produced similar results. The intercept of the resulting regression equation was not significantly different from 7.4% (at zero entanglement). In this case, however, there is another potential problem associated with the variance in the observed entanglement rate as the independent variable. Conventional linear regression assumes zero variance for the independent variable.

A final analysis of this relationship involved rank correlation in which the rates of change were used directly, without taking running means of 3. Again a statistically significant relationship was found ($P < 0.05$).

Correlations Between Rate of Change in Numbers of Adult Males and Entanglement

Counts of adult male fur seals are conducted each year. Territorial males with females are a well-defined component of this population and have been counted since the early 1900's. An analysis of the entanglement rate of females is not possible since no reliable and precise estimates of the total number of females have been produced. However, for males it is possible to test for any correlation between entanglement rates observed in the harvest and reduced recruitment.

Figure 5 shows the rate of change in numbers of adult males with females on their territories plotted against the observed entanglement rate in the male harvest 9 years earlier. This lag was introduced to account for the time required for males to reach active reproductive status in the breeding population (Johnson 1968). The rate of change was calculated using Equation (2) with adult male numbers (raw data) instead of the smoothed data for pup numbers. The relationship is significant as determined by rank correlation ($P < 0.05$), assuming any problems introduced by serial correlation are insignificant. The line shown is the regression equation resulting from the application of the equations in the Appendix.

Age Composition of Entangled Versus Nonentangled Males

Young fur seals appear to become entangled at greater rates than older animals (Fowler 1984a). Work by Japanese scientists supports this (North Pacific Fur Seal Commission 1984, p. 39). Using captive animals and video recording equipment at the Izo Mito Oceanarium in Japan, it was noted that the younger animals (mostly females) become entangled more often than older animals.

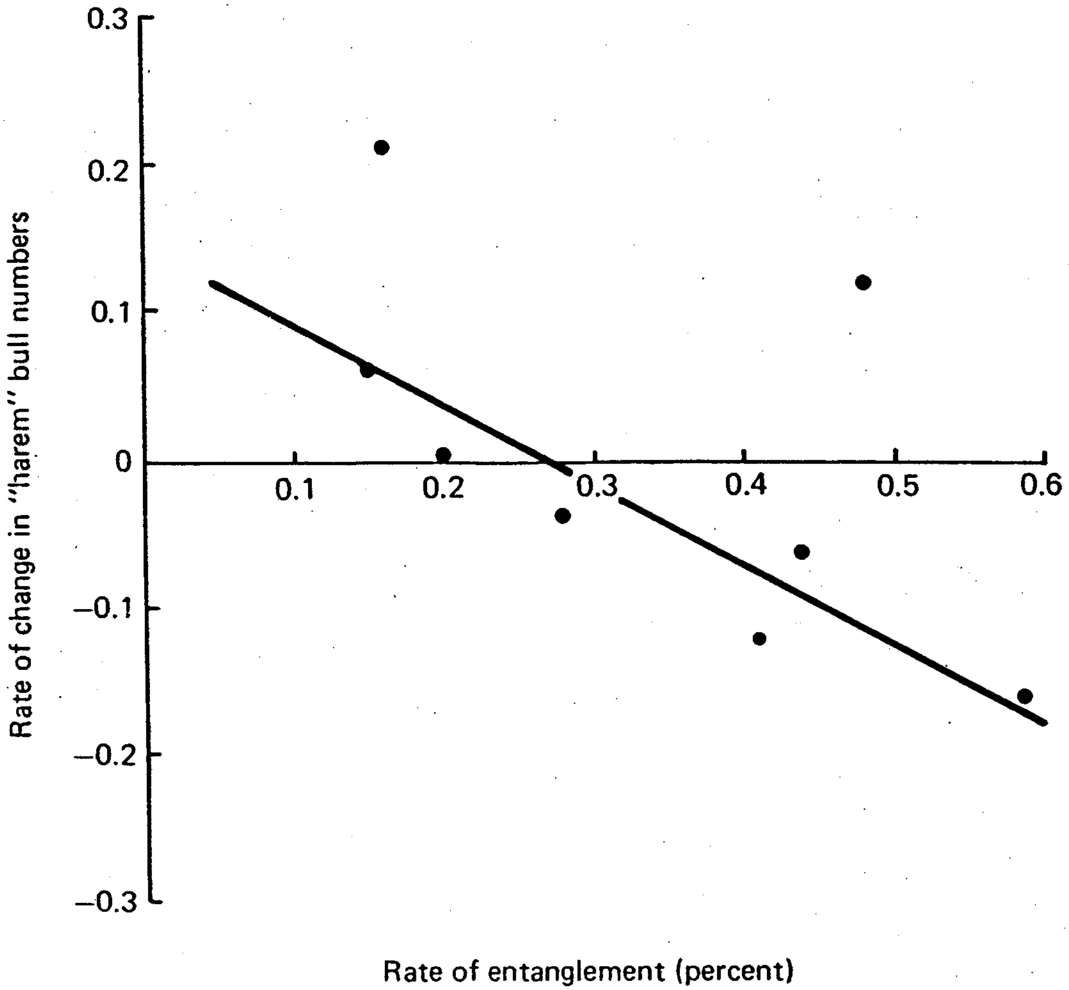

Figure 5.--The correlation between the rate of change in territorial male fur seals with females at St. Paul Island, Alaska, and observed entanglement 9 years earlier.

If the animals of harvestable age are subject to entanglement-caused mortality, the age composition of entangled animals in the harvest should differ from that of unentangled animals. If young animals suffer more of this type of mortality, the age composition of young entangled animals should differ from that of two other groups. First, their age composition would be expected to differ from that of unentangled animals of the same age. Secondly, it would be expected to differ from the age composition of older animals regardless of entanglement. Thus, assuming that the probability of being taken in the harvest is independent of being entangled, the ratio of 3-year olds to 2-year olds in the harvest should be the same for each group (entangled and nonentangled) if no additional mortality occurs among the entangled animals.

Table 1 is a presentation of the number of animals in each age category, broken down by whether or not they were entangled, for the 1982 harvest of males (Scordino and Fisher 1983). A chi-square contingency test shows that the distributions of the two categories are not the same. The ratio of 3-year olds to 2-year olds is different for the two categories.

Table 1.--Age composition of the harvest of entangled and unentangled male fur seals on St. Paul Island, Alaska, 1983 (from Scordino and Fisher 1983).

Age	Number (percent of total in category) Entangled	Unentangled
2	13 (13)	2,078 (8)
3	44 (43)	15,167 (61)
4	30 (30)	7,046 (29)
5	6 (6)	517 (2)
>5	8 (8)	23 (<1)
Total	101	24,831

No attempt is made to drive entangled 2- or 3-year-old animals for harvest in preference to unentangled animals of the same age (J. Scordino pers. commun.). It seems safe, then, to assume that, within each age class, both entangled and unentangled animals have equal probabilities of being harvested. Under these conditions, the ratio of 2-year olds to 3-year olds in each category should be the same after applying a conversion factor to account for any difference (D) which presumably would be due, at least in part, to mortality:

$$D\frac{13}{44} = \frac{2078}{15167} \qquad (4)$$

$$D = 0.46 \qquad (5)$$

The entangled animals in this sample have an estiamted 54% (1.0 - 0.46 = 0.54) lower survival rate between the ages of 2 and 3 than the natural mortality experienced by the unentangled animals. This difference could be the result of several factors including the loss by the seal of its entangling gear, entanglement-caused mortality, or a violation of the assumption of equal probability of being taken (differential recruitment).

These data are consistent with the conclusion that younger animals are more prone to entanglement-related mortality than are older animals. As seen in Table 1, older age classes do not show the difference in age distribution between the entanglement categories that are observed between 2 and 3 primarily because older entangled animals are actively selected for the harvest. Also, data presented by Scordino (1985) indicate that older animals may not experience as much entanglement-caused mortality as is indicated for 2-year olds above. If animals (including females) between birth and the age of 2 are more prone to entanglement than older animals, only part of the 54% reduced survival shown need be attributed to entanglement-caused mortality to be of sufficient importance to cause the decline.

Entanglement and Recent Changes in the Age Composition of the Harvest

The mean age of the harvest animals taken on St. Paul Island has declined since 1970 as indicated by an increase in the portion of 2-year-old animals and a decrease in the portion of 4-year olds (Fowler 1984b). This change may have been due to either a change in survival or age-specific utilization rates. If utilization rates are consistent, an index of survival can be obtained by relating the numbers of animals of one cohort to the number of animals from the same cohort taken the previous year.

Such an index was calculated for all cohorts and normalized to produce comparable values. The results are plotted in Figure 6 and show an increasing trend in the index of survival for the period over which the population declined in response to the female harvest (1956-68). Since 1970, however, the survival index of animals between the ages of 2 and 5 has declined nearly to levels observed in the 1960's.

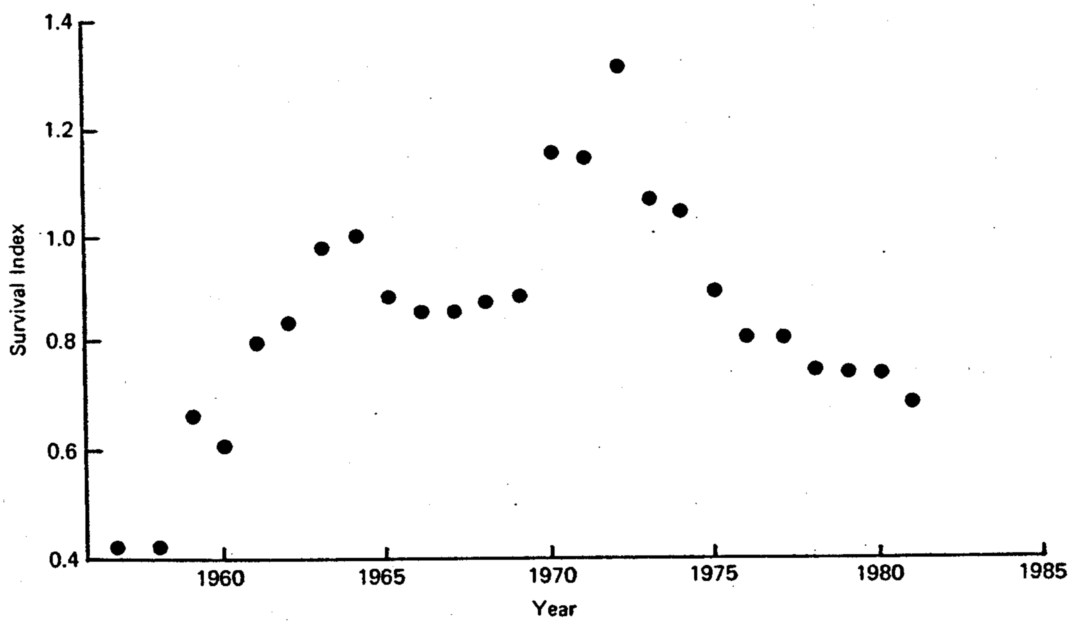

Figure 6.--A survival index for 2- to 5-year-old male fur seals as calculated from the age composition of the harvest, 1957-81, St. Paul Island, Alaska.

The declining trend in the index of survival implied by these data coincides in time with the occurrence of observed entanglement. Any relationship between the two variables is supported only by this temporal correspondence, however. There is no statistically significant correlation between the variables. It is possible that survival has changed little and that instead the harvest rate of males has increased in parallel with changes observed for other species (Fowler 1980) for which effective effort increases as the harvest population declines. Data presented by Scordino (1985) indicate that mortality attributable to entanglement among older males is less than for younger animals. If this is the case, changes in the age structure may be wholly a product of gradual changes in the harvest to result in increasing utilization rates among younger animals. This is a conclusion reached by York (1985).

DISCUSSION

Attempts to estimate entanglement-caused mortality have been based on limited data (Fowler 1982a, 1982b). Assumptions about the size composition of net fragments involved in entanglement, the mortality rate of animals entangled in small debris, and the degree to which females are entangled were necessary to arrive at these estimates. Further analysis and more recent information showed that earlier estimates were probably low (Fowler 1984a), but resulted in no more accurate estimates. However, consistency among the various estimates supports the view that there is a cause-and-effect relationship behind the correlations in Figures 3, 4, and 5. Nevertheless, it remains difficult to produce precise estimates of the mortality rates caused by entanglement.

Recent information emphasizes that entanglement is more of a problem for young seals than for older seals. Work by Japanese scientists indicates that young animals exhibit a greater tendency to investigate debris and become entangled than do older aniamls. (An observation made at the Honolulu Workshop on the Fate and Impact of Marine Debris, November 26-29, 1984. Also see page 39 of North Pacific Fur Seal Commission 1984.) Their work also shows that young females become entangled and that animals of both sexes often can free themselves once entangled in debris. The reaction of the population on St. Paul Island is consistent with higher juvenile mortality as indicated by the importance of time lags between observed entanglement rates and reduced pup production (presumably because of reduced recruitment of females) and the decline in the numbers of adult males. The difference in age structure between entangled and unentangled animals in the harvest is also consistent with lower survival for entangled animals between ages 2 and 3 than for unentangled animals.

If most entanglement involves animals in their first few months at sea, and if seals in small net fragments suffer mortality at the rate indicated by the age distribution of harvested animals, it is possible that only 9.7% of the animals entangled in smaller debris return to be seen as 3-year olds ($0.46^3 = 0.097$ from the 0.46 survival of Equation (4) applied over 3 years). The total entanglement in small debris would be about $0.003/0.097 = 0.031$ or 3.1% (0.003 being the approximate fraction of 3-year olds in the harvests that are observed entangled, Table 1). Accounting for the size composition of the net fragments, 15.5% ($0.031/0.2 = 0.1555$) of the young seals may become entangled. (By making the same assumption as in previous work (Fowler 1982a, 1982b, 1984b) that the probability of animals getting caught is independent of net fragment size and that beach samples represent the composition of debris at sea, it is possible to account for animals which have died and not returned to land.) The majority, 90.3% ($1.0 - 0.097 = 0.903$), of these would die.

It is possible that the correlations presented in this paper are the fortuitous result of other correlated causal factors which have so far gone unnoticed, or that chance alone has resulted in the other observations that indicate entanglement could account for the current decline. The correlations observed might also be affected by the analytical procedures. However, we are not faced with only one or two isolated cases of this nature. There is a growing number of such factors. They include the several correlations between entanglement and the decline, the several estimates of mortality due to entanglement which are consistent with each other and with the decline in fur seal herd, and the ways such factors combine into quantitative models which mimic recent dynamics of the fur seal population. When considered collectively, these observations indicate that entanglement-caused mortality is a major contributing factor in the decline in the fur seal population of the Pribilof Islands. So also do details concerning the size composition of entangling debris, beach samples of debris, captive animal studies, studies of the occurrence of debris at sea, and studies of age composition of entangled animals in the harvest. The levels of mortality consistent with the data, in each case, are sufficient to explain the decline as verified through modelling studies (Swartzman 1984; Trites 1984). It is unlikely that such a combination of circumstances would occur if entanglement were not causing or contributing significantly to the present decline.

There exists a number of other factors which may be considered of potential importance in the decline of fur seals on the Pribilof Islands. These include such things as emigration, predation, diseases, the commercial harvest of males, reduced reproductive rates, reduced food supply, and toxic substances. Although there are often limited data, and further research is needed, the existing information generally indicates that the influences such factors are having on the population are not abnormal and that presently there is little or no reason to believe they are contributing to the decline (Fowler 1985). Some possibilities are inconsistent with observed changes in the population. For example, reduced food supplies are inconsistent with the density dependent responses of increased growth rates (body size) and increased pup survival (Fowler 1984b). A correlation exists between estimated juvenile survival and eastern Pacific sea-surface temperatures (York 1985). Such a correlation may imply an effect through the food chain which could be contributing to the decline but would again be inconsistent with increased body size. Further exploration of these possibilities is presented in Fowler (1985) where it is again emphasized that further research is needed.

CONCLUSIONS

Entanglement and several aspects of the population dynamics of the northern fur seal population on the Pribilof Islands, Alaska, are significantly correlated as indicated by data from St. Paul Island. The difference between the current rate of decline in pup numbers and the rate of increase experienced in the 1920's (when the population was last at current levels) is explained through a correlation between rates of change in pup numbers and entanglement observed in the male harvest (Fig. 4). Similar correlations exist for the rate of change in the count of breeding males with females in their territories (Fig. 4). Unexpected increased in juvenile mortality (estimated for males and assumed to apply to females as well) are explained through correlations with observed entanglement (Fig. 2).

Analyses of the limited data emphasize that mortality rates caused by entanglement are consistent with those which would cause the current population trend. Furthermore, most of the existing information indicates that entanglement-caused mortality is primarily a problem for animals younger than 3 years of age, but involves most age classes to some extent.

Although it seems clear that entanglement is an important factor, limited progress has been made in providing accurate estimates of entanglement-caused mortality. The precise extent to which entanglement is contributing to the decline of northern fur seals on the Pribilof Islands has not been determined. There is a continuing need for studies to determine the degree to which females are involved in entanglement and estimates of resulting mortality.

Because of the consistency between the observed rates of entanglement and recent population trends, future studies should be directed toward determining better estimates of the entanglement-caused mortality by age and sex. Because of limited direct cause-and-effect information, and recognizing that other contributory causes of the decline may exist, future research should include studies of possible changes in reproductive rates, the effect of diseases and toxins, and changes in the fur seal's ecosystem. The need for studies of the influence of environmental conditions is emphasized by the recent work of York (1985).

ACKNOWLEDGMENT

Previous drafts of this paper were reviewed by Joe Scordino, Steve Zimmerman, Howard Braham, John Bengtson, Anne York, Robert Francis, Roger Pearson, Sharon Giese, Susan Scott, Pamela Wilder, William Lenarz, Tim Smith, and two anonymous reviewers. I am grateful to these individuals for their help and comments.

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APPENDIX

The following equations were used to perform regression analysis for this paper and resulted in the regression lines shown in the figures. In each case x_i is the ith observation of the independent variable and y_i the corresponding observation of the dependent variable. These equations result from assuming both variables show a nonzero variance and minimizing the perpendicular distance between the data point and the line of regression. The regression equation for the underlying relationship is assumed to be:

$$Y = a + bX \tag{5}$$

The estimate of the intercept (a) is:

$$a = \left(\sum_{i=1}^{n} y_i - b \sum_{i=1}^{n} x_i \right) / n \tag{6}$$

where n is the sample size of the points defined by x and y and b is estimated by:

$$\hat{b} = \min \left(\frac{-q \pm \sqrt{q^2 + 4p^2}}{2p} \right) \tag{7}$$

where

$$p = \sum_{i=1}^{n} x_i y_i - \frac{\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n} \tag{8}$$

and

$$q = \left(\frac{\left(\sum_{i=1}^{n} y_i \right)^2}{n} - \sum_{i=1}^{n} y_i^2 \right) - \left(\frac{\left(\sum_{i=1}^{n} x_i \right)^2}{n} - \sum_{i=1}^{n} x_i^2 \right) \tag{9}$$

STELLER SEA LION ENTANGLEMENT IN MARINE DEBRIS

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ABSTRACT

Observations of Steller sea lions involved in entanglement of marine debris have been made throughout the Gulf of Alaska and in southeastern Alaska. Two categories of debris, closed plastic packing bands and net material, account for the majority of instances of entangled animals. Net material appears to be primarily from fishing trawls, although the exact origin remains obscure.

Photographic evidence and necropsies show extensive tissue damage suffered in the neck area of entangled animals. Some animals have scars on the neck indicating recovery from entanglement. However, severity of wounds observed suggests that, in many cases, the encounter is fatal.

In theory, sea lions swim forward only, and they apparently seldom "back up," thus, once foreign material encircles the neck, there is little likelihood of it being removed. Polypropylene or plastic netting material or packing band material is known to be long lasting and, therefore, can remain on the animal's neck as an abrasive irritant over long periods. Decay of the foreign material possibly could be hastened by agents which may be produced from the necrosis of tissue allowing some animals to eventually shed the entanglement material, and if the damage is not too severe, survive the encounter.

Two beaches in the northern Kodiak Archipelago were surveyed for marine debris. Emphasis was placed on material which was considered to have potential for entanglement with sea lions. One beach was surveyed on the west side of Afognak Island which was exposed to the drift mechanisms of Shelikof Strait, and the other beach surveyed was exposed to the Gulf of Alaska and the North Pacific Ocean.

Debris noted was divided into four categories: nets, plastic bands, ropes, and buoys. The first three categories were further divided as follows: nets--potentially entangling since >1 m^2 and not entangling since <1 m^2; plastic bands--open or closed loop; ropes-->1 m and knotted on the ends as potentially

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

entangling and <1 m or not knotted on the ends as not entangling. Buoys by themselves were not considered as potentially entangling and lines attached to buoys were considered under the category of ropes. Some interesting differences were noted between the two beaches. Substantially more net material >1 m^2 was observed on the beach in Shelikof Strait than the beach exposed to the North Pacific Ocean. Most plastic band material found was cut. One beach had no closed packing band loops. Slightly less than half of the rope material found was potentially dangerous to sea lions and far more rope material was found on the beach exposed to the Pacific Ocean than the beach exposed to Shelikof Strait. More buoys were also found on the Pacific Ocean beach.

INTRODUCTION

The Steller sea lion, Eumetopias jubatus, is a conspicuous, large pinniped which inhabits the North Pacific Ocean and adjacent seas. Sea lion habitat in these areas extends from approximately 25 m above mean high tide at rookeries and haul-out areas to the continental shelf break on the high seas. They are highly mobile animals and movements exceeding 1,500 km have been documented (Calkins and Pitcher 1982). During May through July, Steller sea lions gather on traditional rookeries to pup and breed. Other haul-out areas continue to be used during this time by nonreproductive animals. Although there are at least 100 locations in the Gulf of Alaska and southeastern Alaska where sea lions haul out on a regular basis, only 11 of these are major breeding concentrations, or rookeries (Calkins and Pitcher 1982). The largest sea lion concentrations in the world are found near Kodiak Island.

Steller sea lions eat primarily off bottom, schooling fishes such as walleye pollock, Theragra chalcogramma, and Pacific cod, Gadus macrocephalus (Pitcher 1981). They are often sighted in the vicinity of fishing activity for these two species. Observers have even speculated that sea lions are attracted by noises generated during retrieval operations of trawls (Loughlin and DeLong 1983).

The Alaska Department of Fish and Game has carried out an extensive research project on Steller sea lions which involved observations and data collections on the biology and life history of sea lions including observations of entangled animals. This work was primarily supported through Federal funds, initially through the Outer Continental Shelf Environmental Assessment Program which was funded to provide information before offshore oil lease sales and subsequent offshore oil exploration and development. In recent years, sea lion research by Alaska Department of Fish and Game has been supported with funds provided by the National Marine Fisheries Service, Alaska Region.

Part of the information presented here was gathered during other studies. The entanglement observations are entirely incidental to other sea lion studies. Information presented on debris from beach surveys in the Kodiak area was not intended to be a final report on work performed. Indeed this report is only intended as an interim progress report. The beach surveys were primarily designed to provide baseline data to design better future study.

STUDY AREA

The information provided in this study was collected in the Gulf of Alaska, primarily in nearshore areas bounded in the southwest by Unimak Pass and in the southeast by Dixon Entrance (Fig. 1).

Two beaches were chosen to be surveyed for debris considered potentially harmful to sea lions (Fig. 1). Debris considered potentially harmful was based upon observations of entangled sea lions. The first beach (beach 1) was located in Marmot Strait, on the east side of Afognak Island, north of Kodiak Island. This beach was chosen because it was thought to be exposed to the North Pacific Ocean directly. The second beach (beach 2) was located north of Malina Bay on the west side of Afognak Island. This area was chosen because it is exposed to Shelikof Strait between the Kodiak Archipelago and the south side of the Alaska Peninsula.

METHODS

Observations of entangled animals were made incidental to other studies carried out at rookeries and haul-out areas. Animals were photographed whenever possible, and, in one case, an animal was collected (in conjunction with other studies) which had a packing band around its neck. Most information on sea lion entanglement available at this time has been primarily anecdotal and no attempt has yet been made to quantify mortality involved in entanglement. Data presented here are not sufficient to provide statistically valid analysis.

Beaches were surveyed on 23 May and 24 May by six people at beach 1 and four people at beach 2. The beaches were arbitrarily divided into unequal sections and each person surveyed a single section. Thus beach 1 was divided into six sections, and beach 2 was divided into four sections. Wherever possible, each person removed debris which was considered to have potential for entanglement with Steller sea lions. The debris considered as potentially entangling to sea lions was divided into three categories; nets, plastic bands, and ropes. Although not considered harmful by themselves, buoys were also surveyed. The three categories were further divided as follows: nets--potentially entangling as >1 m^2; plastic bands--open or closed loop; ropes-->1 m and knotted on the ends as potentially entangling, and <1 m not knotted on the ends as not entangling. Buoys by themselves were not considered as potentially entangling; and lines attached to buoys were considered under the category of ropes.

Some net fragments and large pieces of rope were either partially buried or sufficiently tangled on stationary objects such as trees or large rocks to make them impossible to remove. In these instances, we removed as much as possible and noted the location of the remainder. The collected debris was taken to a central location where it was catalogued and stored above the highest storm tide level to prevent its return to the beach. In some cases, buoys without ropes were placed above maximum storm tide level near the locations they were found to save time.

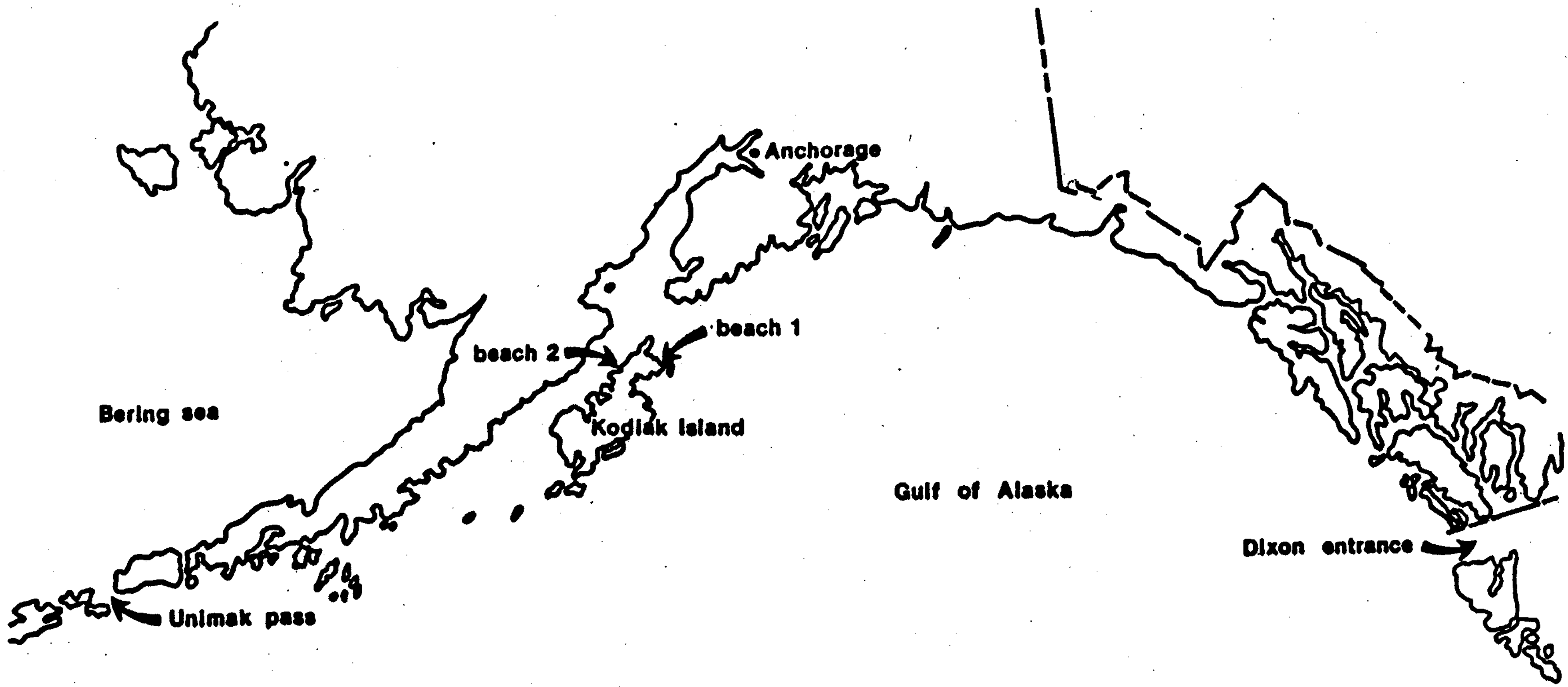

Figure 1.--Study area for Steller sea lions. Arrows indicate beaches surveyed.

RESULTS AND DISCUSSION

From my observations and photographs there appear to be two categories of debris which account for the majority of instances of entangled animals: closed plastic packing bands and net material. Both categories seem to involve animals 2- to 3-years old and older. Both sexes appear to be susceptible although more adult females have been observed entangled and no adult males. We have no records of neonatal sea lions being entangled. Perhaps the reason why few young animals are seen entangled is that entanglement results in extremely high mortality in this age class and therefore would not be seen, or they do not normally become entangled. In the case of closed packing bands, sea lions probably become entangled as they attempt to swim through them either from curiosity or accidently. Once the band is over the head, it probably remains there until it decays, or is broken, or kills the sea lion. It is my opinion that sea lions probably do not have the ability to remove debris once they become entangled. However, the one possible way a sea lion may remove a band or net from the neck is by breaking it with a claw.

Packing bands around the neck cause tissue damage in two ways. If the animal is a subadult when it acquires the band, and if the band is sufficiently small, it may cut into the tissue as the sea lion grows. Often when animals are sighted they have what appears to be an open wound, completely encircling the neck. At times it is difficult to determine if the foreign material has been removed or if the animal has grown around it. It is even possible that some of the healed wounds we see may still have some foreign material ingrown.

The other possibility for tissue damage from packing bands is simple abrasion. If the band is too large to cause constriction, or if the animal is already an adult and has stopped growing, then the band is generally visible and the injury is often characterized by being noncontinuous around the neck. Often this type of injury is either directly on the dorsal and occasionally on the ventral surface of the neck. This type of injury is probably caused from an abrasive action generated while the animal is swimming, either from water pressure forcing the band against the neck or pulling it from the opposite side.

In addition to curiosity sea lions can be entangled in floating net material and by attempting to haul out on it or remove fish from it. They may also become entangled in trawl nets being actively fished and either break free or are cut free, thus retaining a section of net on their bodies. Net fragments are most often seen around the neck, although occasionally a fragment may cover other parts of the body. The majority of net fragments which I have been able to identify on sea lions have been of the type used in trawl gear in the high seas groundfish fishery. I have not identified gill net or seine gear of the type used in nearshore commercial salmon fisheries entangled on sea lions. It is certainly possible for sea lions to become entangled in nearshore commercial salmon gear since extensive fisheries take place in this area, although this does not appear to be a major problem.

Net fragments entangled on sea lions are usually small pieces (probably <2 m^2) around the neck and usually appear to be tightly lodged. Occasionally long pieces of net trail from the neck. Injuries from net fragments appear to be similar to those caused by smaller plastic bands. There is often a continuous wound encircling the neck where the net is lodged, and a band of necrotic tissue on either side plus often what appears to be scar tissue beyond that. It is possible that some of the healed wounds we see that we intrepret as a recovery from an entanglement are from net material which the animal successfully escaped.

Table 1 shows the debris collected during the two beach surveys. As can be seen from Table 1, substantially more net material >1 m^2 was found on beach 2 than on beach 1. Apparently many people are cutting plastic bands before discarding them into the ocean, as far more cut bands were found than closed loops. In fact on beach 1 no closed loop bands were noted. A great deal of rope was found on both beaches although beach 1 had the most. Slightly less than half of the total rope material found was considered potentially dangerous to sea lions.

Table 1.--Marine debris collected on two beaches of Afognak Island, Alaska, May 1984.

	Nets		Plastic bands		Ropes		Buoys
	Potentially entangling >1 m^2	Not entangling <1 m^2	Open	Closed	Potentially entangling 1 m and knotted	Not entangling 1 m or not knotted	Not entangling
Beach 1	8	9	8	0	23	24	30
Beach 2	17	3	3	3	14	21	23

The decision to divide net and rope fragments into the above categories was arbitrary. It was felt that although 1 m^2 is a sizable piece of net, it seems unlikely that a sea lion would initially become entangled in net fragments much smaller that 1 m^2. Although we do see sea lions with net fragments which appear to be smaller than 1 m^2 around their neck, it is my opinion that when acquired, the fragments were probably larger. Rope fragments >1 m^2 and knotted were considered potentially dangerous to sea lions because we have seen many rope fragments which have frayed and unraveled to a point where they resemble large bundles of monofilament. These appeared to have substantial potential for entanglement.

The beaches surveyed were selected from charts of the coastline; however, after surveying the actual beaches, it appeared that beach 1 may not have been a typical beach exposed to the Pacific Ocean and North Gulf of Alaska. The large amounts of rope material and buoys, and smaller amounts of net, particularly trawl net may be indicative of the more localized crab fishery in Marmot Bay and Marmot Straits rather than the north gulf as a whole.

At present I am unable to fully assess the impact of marine debris on Steller sea lions. There are several aspects of the problem which need to be more completely investigated before we can accurately predict the actual effects on the sea lion population. A number of beaches should be surveyed within important sea lion habitat to determine the extent and accumulation rates of debris which are potentially dangerous to sea lions. The beaches should be selected relative to the major drift patterns of the North Pacific, the southwestern Gulf of Alaska, Shelikof Strait, and the southeast Bering Sea. Several beaches should be selected to avoid localized effects. The amounts of potentially entangling materials presently adrift in the same areas mentioned above would provide a more complete understanding of the problem, although I believe this type of information is extremely difficult to acquire. I also consider it worthwhile to estimate the amounts of material being deposited into the oceans. Such an estimate might be derived through interviews with fishermen. Finally, an important aspect which can be measured is an estimate of the percent of sea lions entangled in marine debris and from this an estimate of debris caused mortality. I expect to begin a study designed to determine this estimate by surveying large numbers of sea lions on rookeries and haul-out areas, recording all observed incidents of entanglement by sex and age class where possible, and recording the total numbers of animals present by sex and age class.

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ENTANGLEMENT OF PINNIPEDS IN NET AND LINE FRAGMENTS AND OTHER DEBRIS IN THE SOUTHERN CALIFORNIA BIGHT

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ABSTRACT

We documented cases of pinnipeds with various kinds of debris entangling them at San Nicolas and San Miguel Islands, California, from 1978 through 1982. In 1983 and 1984 we conducted systematic surveys to document the frequency of entanglement of northern elephant seal, Mirounga angustirostris; California sea lion, Zalophus californianus; and harbor seal, Phoca vitulina richardsi, in marine debris. Approximately 0.08% of the animals in each population had materials encircling their necks or torsos while another 0.06 to 0.10% had scars indicating previous encounters with entangling materials. Encounter with marine debris could be confirmed as the cause of entanglement in only a few cases; trawl net fragments and plastic packing bands were the entangling debris in these instances. Most entanglements appeared to be related to interactions of pinnipeds with operational commercial and perhaps sports fisheries rather than with debris. Although some pinnipeds in southern California waters are apparently being entangled by marine debris, the magnitude of debris-related mortality remains unknown. Assessment of the impact of marine debris on pinniped population will require 1) that entanglement during fishing operations be distinguished from encounter and entanglement with discarded or lost gear fragments and other debris and 2) determination of mortality rates of debris-entangled pinnipeds.

INTRODUCTION

The interactions between marine mammals and commercial or sport fisheries that result in injury to or death of animals have been grossly divided into two types. "Incidental take" refers to mortality of marine mammals that become tangled or trapped in operational fishing gear and either drown or are shot or clubbed before they are disentangled or cut free from the gear. It may also refer to shooting of animals by fisherman at sea or on rookeries or collision of vessels (or their propellers) with marine mammals. "Entanglement" has been used by some authors to describe the phenomenon of animals becoming entrapped in discarded net fragments (i.e., "passive fishing gear") and other debris as well as in active

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

fishing gear. Fowler (1982), however, reserved the term "entanglement" to refer to marine mammals being wrapped or caught in debris (including fishing gear) that had been lost or discarded at sea. Since marine mammals caught in actively fished gear may be cut free, leaving some net or line fragments attached to them, it is often difficult to confirm that certain kinds of entangling material observed on animals were actually debris when the animals encountered them. Here we use the terms "entangled" and "entanglement" to describe all cases of man-made items encircling the bodies of pinnipeds observed during our surveys. We do, however, consider the possibility that pinnipeds may have encountered these items while interacting with active fishing gear rather than debris at sea.

The extent of interactions of pinnipeds with commercial and sports fisheries has received much attention recently (e.g., Northwest and Alaska Fisheries Center 1980; Anonymous 1981; Everitt et al. 1981; DeMaster et al. 1982; Fowler 1982; Miller et al. 1983; Swartzman and Haar 1983; Metleff and Rosenberg 1984) primarily because these interactions result in damage to fishing gear and loss of marketable fish. The effects of pinniped mortality from fishery interactions (including entanglement in gear and gear debris) on the status and trends of pinniped population have, however, received limited attention. Anecdotal observations have been reported of pinnipeds with various kinds of man-made items encircling their necks or torsos; tissue damage has been observed in many cases. Few cases, however, have been observed or reported of pinnipeds that have died as a result of entanglement in debris. The effects of pinniped entanglement in marine debris on population trends have therefore been difficult to assess. Interpretations of the potential effects have often been limited by a lack of information on the proportion of a population that becomes entangled in debris, the sex and age structure of those entangled animals, and the fate of entangled animals.

Fowler (1982) summarized systematic observations on the occurrence of net fragments and other debris entangling northern fur seal, Callorhinus ursinus, at the Pribilof Islands since the mid-1960's and examined the potential effects of mortality resulting from entanglement on population trends. Entanglement of other species of pinnipeds has been noted by several authors (e.g., Kenyon 1981; Bonner 1982; Allen and Huber 1983; Canil and Canil 1983; Henderson 1983; Huber et al. 1983) but most accounts are anecdotal; the magnitude of entanglement by various types of marine debris and the extent of mortality resulting from entanglement are unknown.

Since 1978, we have made ground censuses of pinniped populations at San Nicolas and San Miguel Islands at intervals varying from weekly to monthly (e.g., Stewart 1980, 1981; Stewart and Yochem 1984). Before 1983 we noted any animals observed on these censuses that were entangled in debris. We recorded the types of debris entangling animals as well as that found on beaches. The number of entangled animals observed during that period was low but our surveys of entangled animals were not systematic and therefore the data are not useful in assessing the frequency of entanglement in each population.

In 1983 we began systematic surveys of northern elephant seal, Mirounga angustirostris, California sea lion, Zalophus californianus, and harbor seal, Phoca vitulina richardsi, at San Nicolas Island (SNI) and of northern elephant seal and harbor seal at San Miguel Island (SMI) to document the frequency of pinniped entanglement in various kinds of debris. We also continued to document debris (type, amount, size) that had washed ashore on these islands. Surveys for entangled animals were conducted simultaneously with, but independently of, population censuses. We chose small groups of animals in each census area (see Stewart and Yochem 1984) and surveyed them using binoculars or a spotting scope. We also used a Celestron C-90 spotting scope to photo-document entangled animals. At SNI, where most of the work was concentrated, pinniped rookeries and hauling areas extend along approximately 13 km of coastline on the south side of the island. The populations are naturally subdivided into smaller groups (census areas) along this area by topography. In each census area we surveyed small groups of seals and sea lions and recorded the number examined, the number entangled, and the number scarred from prior entanglement. We classified each animal examined by age and sex; only those animals whose entire bodies could be seen clearly were included in the "entanglement survey."

RESULTS AND DISCUSSION

Although our surveys were often more frequent, we used only a single survey per month (usually mid-month) to determine the magnitude of entanglement for each species (Tables 1, 2, and 3). We assume that each monthly sample is independent of other monthly samples and therefore that each sample is of a unique number of animals. Any tendency for entangled animals to spend more time hauled out than nonentangled animals may bias the analysis and result in inflated estimates of entanglement. The season of the sample may also affect estimated entanglement rates if entangled animals remain at the rookeries longer than do nonentangled animals of similar age and sex classes that may migrate and be entirely absent or in low abundance at certain seasons. Combined estimates of entanglement rates then may be more accurate if based on seasonal samples taken throughout the year. Combining all sampling periods, we examined 13,175 sea lions, 11,054 elephant seals, and 1,877 harbor seals. Approximately 0.08% of sea lions, 0.08% of elephant seals, and 0.05% of harbor seals had synthetic items encircling their bodies and an additional 0.10% of sea lions, 0.06% of elephant seals, and 0.05% of harbor seals had scars suggesting previous entanglement with debris or encounters with actively fished nets or longlines. We were generally unable to discriminate among polypropylene, polyethylene, or other synthetic multifilament synthetic materials such as "poly."

Of the 11 sea lions observed entangled, 2 had packing bands (1 plastic, 1 rubber) around their necks, and 5 were entangled in monofilament gill net fragments; 1 yearling sea lion with a gill net fragment tightly constricting its neck was later observed dead. Four sea lions had tangled lengths of monofilament fishing line caught around their necks (Table 4); we did not observe hooks attached to any of the fishing line. Thirteen sea lions had scars encircling their necks; the scar patterns were suggestive of thin monofilament, either fishing line or gill net, rather than of the thicker multifilament materials or more robust packing bands. Therefore, of 24 sea lion "entanglements" observed, 13 (54%) were of animals that had lost the entangling material. In 22 of these 24 "entanglements" it is likely that the sea lions acquired the entangling material or scars during interactions with commercial or sport fisheries. Two of the "entangled" sea lions had apparently been entangled in debris (packing bands).

Table 1.--Incidence of entanglement of California sea lions at San Nicolas Island.

Date	Adult males	Subadult males	Females and juveniles	Yearlings	Pups	Total
Dec. 1983						
Sampled	1	26	721	20	468	1,237
Entangled	0	0	0	0	0	0
Scars	0	0	1	0	0	1
Jan. 1984						
Sampled	0	46	596	83	510	1,235
Entangled	0	0	0	0	0	0
Scars	0	1	0	0	0	1
Feb. 1984						
Sampled	0	115	843	18	518	1,494
Entangled	0	0	0	2	0	2
Scars	0	0	1	0	0	1
Mar. 1984						
Sampled	0	35	389	46	425	895
Entangled	0	0	0	0	1	1
Scars	0	0	0	0	0	0
Apr. 1984						
Sampled	0	0	315	32	218	565
Entangled	0	0	1	0	0	1
Scars	0	0	1	0	0	1
May 1984						
Sampled	16	31	489	62	0	598
Entangled	0	0	0	1	0	1
Scars	0	0	1	0	0	1
June 1984						
Sampled	100	86	626	120	35	967
Entangled	0	1	0	1	0	2
Scars	1	1	0	0	0	2
July 1984						
Sampled	228	355	607	96	340	1,626
Entangled	0	0	0	2	0	2
Scars	1	4	1	0	0	6
Sept. 1984						
Sampled	0	31	1,683	210	501	2,425
Entangled	0	0	1	1	0	2
Scars	0	0	0	0	0	0
Oct. 1984						
Sampled	0	0	234	31	457	722
Entangled	0	0	0	0	0	0
Scars	0	0	0	0	0	0
Nov. 1984						
Sampled	0	78	703	53	577	1,411
Entangled	0	0	0	0	0	0
Scars	0	0	0	0	0	0
Total						
Sampled	345	803	7,206	771	4,049	13,175
Entangled	0(0%)	1(0.012%)	2(0.03%)	7(0.91%)	1(0.02%)	11(0.08%)
Scars	2(0.58%)	6(0.75%)	5(0.07%)	0(0%)	0(0%)	13(0.10%)

Table 2.--Incidence of entanglement of northern elephant seals at San Nicolas and San Miguel Islands.

Date	Adult males	Subadult males	Females	Juveniles	Yearling	Pups	Total
San Nicolas Island							
Dec. 1983							
Sampled	43	51	32	35	115	10	286
Entangled	0	2	0	0	0	0	0
Scars	0	0	1	0	0	0	1
Jan. 1984							
Sampled	111	48	486	0	9	415	1,069
Entangled	0	1	0	0	0	0	1
Scars	0	0	0	0	0	0	0
Feb. 1984							
Sampled	120	56	210	0	4	316	706
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Mar. 1984							
Sampled	18	22	30	0	0	315	385
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Apr. 1984							
Sampled	0	0	310	315	18	65	708
Entangled	0	0	0	1	0	0	1
Scars	0	0	0	0	0	0	0
May 1984							
Sampled	0	0	0	249	75	0	324
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	1	0	0	1
June 1984							
Sampled	0	42	268	26	0	0	336
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
July 1984							
Sampled	24	43	15	10	0	0	92
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Sept. 1984							
Sampled	1	0	0	266	67	35	369
Entangled	0	0	0	0	1	0	1
Scars	0	0	0	0	0	0	0
Oct. 1984							
Sampled	0	8	15	80	15	221	339
Entangled	0	0	0	0	0	0	0
Scars	0	1	0	0	0	0	1
Nov. 1984							
Sampled	5	25	45	178	15	181	449
Entangled	0	0	0	1	0	1	2
Scars	0	0	1	0	0	0	1
San Miguel Island							
Jan. 1984							
Sampled	385	315	975	0	128	1,268	3,071
Entangled	0	0	2	0	0	0	2
Scars	0	0	0	0	0	0	0
Feb. 1984							
Sampled	312	265	865	0	65	1,413	2,920
Entangled	0	0	0	0	1	0	1
Scars	0	1	1	0	0	0	2
Total							
Sampled	1,019	875	3,251	1,159	511	4,239	11,054
Entangled	0(0%)	3(0.34%)	2(0.06%)	2(0.17%)	2(0.39%)	1(0.02%)	10(0.09%)
Scars	0(0%)	3(0.34%)	3(0.09%)	1(0.09%)	0(0%)	0(0%)	7(0.06%)

Table 3.--Incidence of entanglement of harbor seals at San Nicolas and San Miguel Islands.

	San Nicolas Island			San Miguel Island		
Date	Adults and juveniles	Pups	Total	Adults and juveniles	Pups	Total
Dec. 1983						
Sampled	72		72			
Entangled	0		0			
Scars	0		0			
Jan. 1984						
Sampled	65		65	165		165
Entangled	0		0	0		0
Scars	0		0	0		0
Feb. 1984						
Sampled	146		146	315		315
Entangled	0		0	1		1
Scars	0		0	0		0
Mar. 1984						
Sampled	168	14	182			
Entangled	0	0	0			
Scars	1	0	1			
Apr. 1984						
Sampled	210	18	228			
Entangled	0	0	0			
Scars	0	0	0			
May 1984						
Sampled	98	4	102			
Entangled	0	0	0			
Scars	0	0	0			
June 1984						
Sampled	235	19	254			
Entangled	0	0	0			
Scars	0	0	0			
July 1984						
Sampled	115	10	125			
Entangled	0	0	0			
Scars	0	0	0			
Sept. 1984						
Sampled	71	3	74			
Entangled	0	0	0			
Scars	0	0	0			
Oct. 1984						
Sampled	86	0	86			
Entangled	0	0	0			
Scars	0	0	0			
Nov. 1984						
Sampled	63	0	63			
Entangled	0	0	0			
Scars	0	0	0			
Total						
Sampled	1,809	68	1,877			
Entangled	1(0.06%)	0	1(0.05%)			
Scars	1(0.06%)	0	1(0.05%)			

Table 4.--Types of synthetic items observed entangling (E) pinnipeds or believed to have caused scars (S) observed on pinnipeds.

	Monofilament				Polypropylene trawl net		Packing bands		Total	
	Line		Gill net							
	E	S	E	S	E	S	E	S	E	S
Sea lions										
Adult males		2								2
Subadult										
Males		6	1						1	6
Females		3								3
Juveniles	2	2							2	2
Yearlings	2		[1]3				2		7	0
Pups		1							1	0
Total	4	13	5				2		11	13
Elephant seals										
Adult males										0
Subadult										
Males	2	3							2	3
Females	1	3					1		2	3
Juveniles	1	1			1				2	1
Yearlings					2				2	0
Pups	1								1	0
Total	5	7			3		1		9	7
Harbor seals										
Adults	1									1
Juveniles							1		1	
Pups										
Total		1					1		1	1

[1]One of these found dead 5 days after first seen entangled.

Of nine elephant seals observed entangled, four had monofilament fishing line encircling their necks (no hooks attached), one had monofilament encircling its torso, three were entangled in "poly" trawl net fragments, and one seal had a plastic packing band around its neck (Table 4). Seven other elephant seals had scars encircling their necks which appeared to have been caused by monofilament line or gill net. Therefore, of 16 elephant seal "entanglements," 7 (44%) were instances where seals had been entangled by materials (probably monofilament line or gill net from active fishing gear) but had lost the material, presumably when it became brittle and broke loose. Four (25%) of the elephant seals showing evidence of entanglement were apparently victims of debris (three entangled by trawl net fragments, one entangled by a packing band).

One harbor seal (adult) was observed with a thin scar around its neck (apparently from previous entanglement with monofilament) and one juvenile was observed with a plastic packing band encircling its neck.

Our observations suggest that many pinnipeds may be freed from materials entangling them, primarily monofilament fragments (gill net or longline). Trawl net fragments and packing bands may be lost less easily since we have seen no animals with scars suggesting that they had been previously entangled with these kinds of debris. This may suggest that animals that become entangled in trawl net fragments or packing bands have greater mortality rates than those entangled by monofilament fragments or that entanglement rates of seals and sea lions in monofilament (operational and debris) are higher than those for other debris. However, the data are not adequate to test either of these hypotheses. The only entangled animal that we observed dead (a sea lion yearling) was entangled in a monofilament gill net fragment.

We observed and collected samples of debris, representative of each type observed entangling animals, on beaches at San Nicolas and San Miguel Islands (Table 5). In addition, we found other types of debris in small amounts. The most common type of debris found was "poly" line fragments of various lengths (Table 5). Although these fragments, when tangled, are capable of entangling pinnipeds, we did not observe any animals entangled in "poly" line.

Because systematic surveys of pinniped entanglement with marine debris in the Southern California Bight have not previously been reported, our data can serve only as a baseline for comparison with data collected with similar methods in the future. However, when considering the impact of "marine debris" on pinniped populations, care should be taken when considering whether all cases of "entanglement" are debris-related. Packing bands, other nonfishing gear items, and trawl net fragments encircling the bodies of pinnipeds are most likely encountered as debris. Entanglement in monofilament line and small gill net fragments probably occurs most often when animals are caught in actively fished gill net or become tangled in actively fished longline gear. If this is true, then most (86%) of the pinnipeds observed (in the Southern California Bight) that showed evidence of entanglement probably encountered the entangling material while interacting with actively fished commercial fishing gear (apparently monofilament gill nets) rather than as debris. The marine debris that appear to be entangling small numbers of pinnipeds in the Southern California Bight are trawl net fragments (with holes in the mesh) and plastic packing bands. Juveniles appear to be the most likely to become entangled in debris and this may be related to their greater degree of curiosity or playfulness or perhaps to their higher rate of encounter with debris sources. California sea lions and northern elephant seals are migratory and (especially young animals) disperse over long distances (primarily northward from rookeries) during the first several years of life.

Assessment and interpretation of the population effects (in the Southern California Bight) of mortality due to entanglement with marine debris require data on 1) the origin, movement, and fate of various kinds of debris with respect to the dynamics of seasonal sex and age class distributions of pinnipeds in eastern North Pacific waters (i.e., rate of

Table 5.--Weights and dimensions of debris found on beaches (B) or removed (E) from entangled dead or live pinnipeds at San Nicolas and San Miguel Islands.

	Sample							
Types of debris	1	2	3	4	5	6	7	8
Monofilament lines								
Weight (g)	227/E	20/E	12/E					
Diameter (cm)	0.15	0.12	0.05					
Monofilament gill net								
Weight (g)	70/E							
Diameter (cm)	0.10							
Mesh size (cm)	20.3							
Dimensions (cm)	61x55							
"Poly" net								
Weight (g)	100/B	500/E	100/B	100/B				
Diameter (cm)	0.35	0.35	0.35	0.35				
Mesh size (cm)	10.2	26.7	26.7	13.1				
Dimensions (cm)	30x15	91x92	46x58	63x39				
"Poly" line[1]								
Weight (g)	43.5/B	1,174/B	78.4B	883/B	639/B	340/B	144/B	48/B
Diameter (cm)	0.8	0.7	0.5	0.9	0.33	0.12	0.8	1.1
"Poly" gill or trammel net								
Weight (g)	86/B	93/B						
Diameter (cm)	0.2	0.2						
Mesh size (cm)	25.4	25.4						
Dimensions (cm)	91x107	111x106						
Lobster pot floats with line								
Weights (g)	676.4/B	812/B	642/B	1,026/B	467/B	1,121/B	787/B	
Buoys with line								
Weights (g)	2,300/B	1,436/B	3,000/B	3,100/B	1,011/B	1,232/B		
Buoys without line								
Weights (g)	1,856/B	1,204/B	665/B	531/B	564/B			
Other								
Weight (g)	227/E	(SKYRO/Fig. 3)						
Dimensions (cm)								

[1]Representative sample selected from a total of 28 samples collected from beaches.

encounter with debris capable of entanglement) and 2) on the probability of mortality of pinnipeds once they become entangled. Proper interpretation of entanglement and the role of debris in entanglement also require that entanglement resulting from encounters with active fishing gear be distinguished from that resulting from encounters with debris.

ACKNOWLEDGMENTS

The work was supported by the USAF (Contract No. F04701-81-C-0018) and the National Marine Fisheries Service (Contract No. NOAA-84-00038). We thank E. Giffin and R. Dow and his staff for arranging access to San Nicolas Island and R. Delong, T. Loughlin, D. DeMaster, W. Evans, and an anonymous reviewer for commenting on the manuscript. We also thank the University of Hawaii Sea Grant Program for providing support to attend the workshop.

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A REVIEW OF HAWAIIAN MONK SEAL ENTANGLEMENTS IN MARINE DEBRIS

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ABSTRACT

Hawaiian monk seals may become entangled in net fragments and other flotsam carried by currents from the North Pacific to the Hawaiian Islands. Through 1984, 27 entanglements have been observed, and at least 8 additional seals are scarred from entanglements. One of these entanglements was probably fatal, and six would likely have resulted in the death of the seals had biologists not intervened. Although weaned pups comprise only about 11% of the total population, pups were involved in 41% of the observed incidents. Mechanisms to account for this disparity are proposed. Observed entanglements have declined since initiation of a regular program to gather and burn potentially hazardous debris.

INTRODUCTION

The Hawaiian monk seal, Monachus schauinslandi, inhabits the rocky islands and low, coral atolls which extend 1,850 km from Nihoa Island to Kure Atoll in the Hawaiian Archipelago, a region known as the Northwestern Hawaiian Islands. Within this range, land area on which the seals haul out comprises approximately 17.7 km^2, but the offshore reefs surrounding these islands, which the seals frequent to forage, mate, or raise their pups, comprise considerable additional area. The 18.3-m (10-fathom) contour surrounding emergent land in the Northwestern Hawaiian Islands encloses approximately 1,257 km^2 (U.S. Department of Commerce[1]). The Hawaiian Archipelago is situated in the subtropical gyre, and flotsam from the North Pacific could be carried towards the islands by southern movement of water from the eastward flowing North Pacific Current to the westward flowing North Equatorial Current. Fisheries which might serve to generate debris are the high seas squid gill net fishery and the groundfish trawl fishery in the North Pacific and Gulf of Alaska. Trawl fisheries, particularly joint venture operations, may be susceptible to loss of nets and other gear

[1]U.S. Department of Commerce. 1980. Proposed designation of critical habitat for the Hawaiian monk seal in the Northwestern Hawaiian Islands. Draft Environmental Impact Statement, 77 p. + appendices.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

(Low et al. 1985). No Hawaii-based net fisheries exist in the vicinity of the Northwestern Hawaiian Islands.

Except for protracted periods ashore during pupping (approximately 5 weeks) or molting (approximately 2 weeks), an individual seal will generally remain at sea for up to 2 weeks before returning for several days' rest on land (Stone 1984). It is not known how far individuals range from land, but it is during these forays at sea that seals may encounter debris which is either drifting or has become fouled on offshore reefs. Seals, such as recently weaned pups, which remain near emergent land, may also encounter flotsam which has become fouled close to shore. This report will summarize all observed occurrences of monk seal entanglement in fishing debris or other flotsam through 1984, as well as observations of seals scarred in a manner suggestive of previous entanglement.

Observations of entangled seals are dependent on the amount of sighting effort, which is not constant, since the number and duration of visits to the different Northwestern Hawaiian Islands by biologists have varied. No systematic surveys of Hawaiian monk seals were undertaken before 1957. Between 1957 and 1974, biologists visited the islands for only a limited time (several days) to census seals and other biota. Not until 1974, when annual field camps (of approximately 1 month) commenced at French Frigate Shoals, were biologists present at any particular location in the Northwestern Hawaiian Islands for any extended time. Post-1974 sighting effort on each island will be summarized under "entangled seals."

SCARRED SEALS

Seals which become entangled in small pieces of debris may bear scars from injuries inflicted by the constricting item. Such scars generally girdle all or part of the animal's body, around the neck, shoulders, or abdomen, and are easily distinguishable from scars resulting from shark bites. The latter, though sometimes forming long clefts, are more irregular in shape than scars resulting from entanglement. Hereafter "scarred seal" will refer to seals bearing scars resulting from entanglement.

Scarring by debris requires that the entanglement be sufficiently prolonged to cause injury without causing the eventual death of the victim. Because of these conditions, scarred seals represent only one component of the minimum number of seals known to have become entangled, and cannot be used to estimate total incidence. Moreover, given the limited number of haul-out locations and the small population of Hawaiian monk seals, multiple sightings of any individual scarred seal are likely, necessitating added care to identify individual animals.

Scarred seals have been observed primarily at French Frigate Shoals. Kenyon and Rauzon[2] presented photos of two scarred adult seals they saw in 1977. Balazs (1979) also reported seeing two scarred adults during his studies at French Frigate Shoals from 1973 to 1978, one of which was an

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[2]Kenyon, K. W., and M. J. Rauzon. 1977. Hawaiian monk seal studies, French Frigate Shoals, Leeward Hawaiian Islands, National Wildlife Refuge, 15 February to 5 April 1977. Unpubl. rep.

animal previously reported by Kenyon and Rauzon. Schulmeister[3] reported two scarred seals (one male adult, one female adult) present at French Frigate Shoals in 1981, one of which was a seal reported previously. Schulmeister also noted a fresh, rope-inflicted neck wound on a female juvenile. Biologists at French Frigate Shoals in 1984 saw at least four scarred seals: a previously reported male adult, two female subadults, and one juvenile of unknown sex (J. Eliason pers. commun. 1984). Assuming one of the subadults was the same animal as the female juvenile reported by Schulmeister, two additional scarred seals were present at French Frigate Shoals in 1984. Thus, a minimum of seven scarred or wounded seals have been sighted at French Frigate Shoals since 1973.

At Sand Island, Midway, in 1983 the author saw a male subadult bearing a fully healed neck scar resulting from a constricting line or band. This seal had been seen previously at Midway on several occasions in 1983 (C. E. Bowlby pers. commun. 1983). The animal appeared to be in good health.

ENTANGLED SEALS

Although Kenyon (1980) mentioned that he and his co-workers had seen "several" entangled monk seals during their visits to the Northwestern Hawaiian Islands (in the late 1960's and 1970's), the record is not clear whether some or all of these "several" are included in other reports described below. Nonetheless, it is likely that entangled seals were present and observed in the Northwestern Hawaiian Islands before 1974.

French Frigate Shoals

As mentioned above, prolonged presence of biologists at French Frigate Shoals commenced in 1974 with the initiation of annual, 1-month field camps to study green sea turtle nesting activity. These camps represented the only routine observation by biologists until mid-1979 when the U.S. Fish and Wildlife Service established an all-year field station on Tern Island, with a complement of two to four personnel. In 1982 the National Marine Fisheries Service initiated an expanded field program at French Frigate Shoals, entailing camps on islets other than Tern Island, which resulted in an increased presence of observers throughout the shoals.

Balazs (1979) saw one entangled seal, a male subadult, during annual trips to French Frigate Shoals from 1973 to 1978. The seal, seen in 1974, was encircled by a piece of plastic strapping, which appeared to be cracking, fraying, and likely to eventually break. Since the strap had not inflicted a wound, the individual seal was not recognizable by means other than its "collar." Thus the animal's fate is unknown.

In 1977 Kenyon and Rauzon (footnote 2) witnessed an adult seal of unknown sex investigating a polypropylene line being used to mark a shark fishing station. The seal repeatedly swam through a loop which was of sufficient circumference to allow passage of the seal without entanglement.

[3]Schulmeister, S. D. 1982. Summary of Hawaiian monk seal, Monachus schauinslandi, data collected at French Frigate Shoals from July 1971 through December 1981. Unpubl. rep.

This is the first, and perhaps most definitive, documentation of an investigatory behavior of monk seals which can result in entanglement. In 1979 Balazs (pers. commun. 1985) observed an adult seal on Whale-Skate Island encircled by one loop of a tangle of line. The seal was not injured, indicating recent entanglement in the debris. The loop was posterior to the foreflippers and was too small to pass over the back and rump. The line was removed over the seal's head. The tangle of line did not completely immobilize the seal, but certainly would have impeded the animal's swimming.

In 1980 the first entanglement of a weaned monk seal pup was documented (Andre and Ittner 1980). The pup, of unknown sex, was entangled in a piece of polypropylene net which was itself fouled in water approximately 0.5 m deep. Although the seal could swim sufficiently to remain afloat, its eventual death due to exhaustion or starvation was likely, and biologists released it. The net fragment measured 9 by 2 m with a 15 cm stretched mesh and 2.3 mm twine diameter.

Schulmeister (footnote 3) in summarizing monk seal research at French Frigate Shoals from mid-1979 through 1981, reported two entangled seals. In 1981 a female adult was observed with a piece of "nylon strapping" around her neck. The individual was identifiable on the basis of old scars, and was subsequently sighted free of the strap and suffering no apparent effects. The second entangled seal observed was an adult of unknown sex which was encircled about the abdomen by a single piece of rope. Biologists removed the rope using a boat hook. The rope was pulled off easily and the report makes no mention of a wound, suggesting that the seal was uninjured.

In 1982, Ittner[4] observed a female subadult bearing a fishhook in the lower lip. The hook was of the round type used in the Hawaii-based fishery for snappers and groupers (Ralston 1982) and may have resulted from the seal's encountering gear which was actively fishing. The seal was an identified individual and was subsequently observed to have lost the hook.

The author observed two entangled seals in 1983. On Tern Island a pregnant female seal was seen encircled about the abdomen by a loop of knotted line. The following day, the line was found on the beach where the seal had hauled out. The seal showed no effects of the temporary entanglement and gave birth later in the year. A male pup was observed on Whale-Skate Island entangled about the neck and shoulders by a piece of gray polypropylene net. The pup was 6-7 weeks postweaning and might have eventually lost the fragment during its postweaning weight loss. Nevertheless, the net was likely to inflict a wound in the interim and was removed.

In 1984 two entangled seals were seen. The first, a subadult of unknown sex, was observed with a plastic band tightly encircling the neck (S. Lautenslager pers. commun. 1984). The band was a white, rigid ring, possibly a shard of a plastic bucket, and had abraded a wound through the

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[4]Ittner, R. 1983. The Hawaiian monk seal, Monachus schauinslandi, at French Frigate Shoals, 1982. Unpubl. rep.

skin of the seal. An attempt to restrain the animal and remove the band was unsuccessful (G. Fairaizl pers. commun. 1984). The individual was recognizable by the wound, was never again seen, and, therefore, probably died. The second entangled seal was a male and known to be a yearling from a bleach mark ("GA") which had been applied in 1983 when the seal weaned. The individual was tightly encircled about the neck and shoulders by a fragment of net. The seal would likely have been seriously injured or ultimately killed by the fragment, which was removed.

Laysan Island

Long-term field camps (up to 6 months long) were established annually at Laysan from 1977 to 1980 and from 1982 to 1984. No entangled or scarred seals were reported by field personnel present at the 1977-80 field camps. In 1982 however, Alcorn (1984) observed three entangled seals. Two female weaned pups became entangled in pieces of flotsam. One individual caught its muzzle in a 115-mm diameter plastic ring; the second became entangled about the neck by a life preserver. The third seal, a female subadult, was entangled about the neck by a piece of line and net. All three pieces of debris were removed by field personnel.

No entangled or scarred seals have been observed on Laysan since 1982.

Lisianski Island

Field personnel were on Lisianski for 5 weeks in 1980, for 6 months in 1982, and for 4-5 weeks in 1983 and 1984. The first entanglement observed was in 1980 when a fragment of net was removed from a male subadult (W. G. Gilmartin pers. commun. 1982). The net was tightly constricted and had cut through the dermal tissue, causing a deep wound and surrounding necrosis. The seal had apparently picked up the fragment at a younger age and had "grown into" it. The animal would likely have died as it continued to grow. The individual seal, albeit scarred, was still present at Lisianski as of July 1984.

During the 6-month field camp in 1982, 10 seals became entangled in debris, although 3 of these were encircled only temporarily. Five of the incidents have been reported by Henderson (1984) and involved four weaned pups and one female adult. Three of these pups were entangled in nets and line which were fouled on offshore reefs, effectively immobilizing the victims. The remaining pup and the adult were seen "wearing" net fragments and a tangle of net and line. The adult female escaped after approximately 1 h without assistance; the pups were all freed.

Three other pups became entangled in flotsam in 1982. Stone (1984) reported a pup with a 90-mm diameter plastic ring around its muzzle. T. Johanos (pers. commun. 1983) observed two entangled pups, one of which had a plastic mesh bag (later removed) about its neck and shoulders, while the other was temporarily caught about the neck by a plastic band. A fourth seal, a juvenile, had been caught by this same band earlier on the same day that the pup was encircled. The pup evidently acquired the band shortly after the juvenile lost it.

A male adult was observed with a line encircling its abdomen, but the seal apparently escaped, since the line was subsequently found (D. Alcorn pers. commun. 1984).

In 1983 only one entangled seal was observed. A female pup was encircled about its neck by a blue rubber ring. The ring was removed, and the seal was not injured.

Kure Atoll

Biologists have maintained 6-month camps at Kure Atoll from 1981 to 1984. During this period only one incident of entanglement has been observed. In 1981 Ittner observed an adult of unknown sex apparently entangled in a large piece of net (W. G. Gilmartin pers. commun. 1984). The seal was ashore on "West Point" and may have hauled out atop the mass of net with its neck only recently (and temporarily?) inserted through a hole in the webbing. The animal was released, but the report is not clear if the animal was actually "trapped."

Other Northwestern Hawaiian Islands

Although long-term field camps have been established at other locations in recent years (Pearl and Hermes Reef 1983-84; Necker Island 1983), no net-scarred or entangled seals have been observed at any of these sites.

SUMMARY AND CONCLUSIONS

The number of incidents of seal entanglements observed since 1974 are summarized in Table 1. A total of 27 incidents were observed, and an additional 8 seals bear scars resulting from entanglement. It is not known whether any of the entanglements observed were repeat occurrences involving the same seal. Nonetheless, considering the years, the locations of occurrences, and the approximate ages of the seals affected, the 27 events certainly involve at least 19 individuals. The current population likely numbers between 1,000 and 1,500 in any one year, and there are no data to indicate that certain seals have more propensity to investigate debris than do others. It is therefore probable that the 27 incidents, in fact, represent entanglements of 27 different seals. The eight scarred seals are certainly eight different individuals. (The seal scarred as a result of its 1980 entanglement on Lisianski is included as "entangled.") Thus the total number of observed entanglements and seals scarred as a result of entanglement is 35.

No Hawaiian monk seal has ever been observed to die as a result of debris entanglement, nor has an entangled carcass ever been found. Of the 35 entanglement and scarring incidents reported here, only 1 (3%) probably resulted in death of the seal, 6 (17%) were judged to have been potentially lethal without intervention, 17 (49%) resulted in unassisted escape by the seal (including the 8 scarred individuals), and 11 (31%) resulted in rescues of seals which may have been able to ultimately free themselves.

The rate of entanglement throughout the Hawaiian monk seal population cannot be determined at this time. The absolute population size is not known, and data are insufficient to estimate annual reproductive or mor-

Table 1.--Summary of entangled and entanglement scarred Hawaiian monk seals observed through 1984 (FFS = French Frigate Shoals; LI = Lisianski Island).

Year	Location	No. and kind of animal	Incident[1]	Type of material	Mobile(M) or immobile(I)[2]	Fate of seal	Reference	Comments
Pre-1974	Unknown	"Several"	E	Net	M (?)	Escaped	Kenyon 1980	
1974	FFS	1 male subadult	E, shoulders	Plastic strapping	M	Probably escaped	Balazs 1979	
1973-76	FFS	3 adults[3]	S	N/A	N/A	N/A	Kenyon and Rauzon 1977; Balazs 1979	
1977	FFS	1 adult	E, body	Shark fishing line	M	Escaped	Kenyon and Rauzon 1977	
1979	FFS	1 adult	E, body	Line	M	Rescued	Balazs[4]	
1980	FFS	1 pup[5]	E, neck	Net	I	Rescued	Andre and Ittner 1980	Probably would have died.
	LI	1 male subadult	E, neck	Net	M	Rescued	Gilmartin[4]	Seal scarred, alive in 1984; would have died.
1981	Kure Atoll	1 adult	E, neck, body	Net	I (?)	Rescued	Gilmartin[4]	
1979-81	FFS	1 adult	E, body	"Rope"	M	Rescued	Schulmeister 1982	
		1 female adult	E, neck	"Nylon strapping"	M	Escaped	Schulmeister 1982	
		1 female juvenile	S, neck	N/A	N/A	N/A	Schulmeister 1982	
		1 female adult	S, neck	N/A	N/A	N/A	Schulmeister 1982	
1982	LI	4 male pups	E, neck (2), body (1), shoulders (1)	Net and line	I (3); M (1)	Rescued	Henderson 1984	3 probably would have died.
		1 female pup	E, muzzle	Plastic ring	M	Rescued	Stone 1984	
		1 female adult	S, neck	Net and line	I (?)	Escaped	Henderson 1984	Female with pup.
		1 pup and 1 juvenile	E, neck	Plastic band	M	Escaped	T. Johanos[4]	Both seals same band, same day.

Table 1.--Continued.

Year	Location	No. and kind of animal	Incident[1]	Type of material	Mobile(M) or immobile(I)[2]	Fate of seal	Reference	Comments
1982	LI	1 pup	E, neck, shoulders	Plastic mesh bag	M	Rescued	T. Johanos[4]	Probably would have survived.
	LI	1 male adult	E, body	Line	M	Escaped	Alcorn[4]	
	Laysan	1 female pup	E, muzzle	Plastic ring	M	Rescued	Alcorn 1984	
		1 female pup	E, neck	Life preserver	M	Rescued	Alcorn 1984	Probably would have survived.
		1 female subadult	E, neck	Net and line	M	Rescued	Alcorn 1984	Probably would have survived.
	FFS	1 female subadult	E, lip	Fish hook	M	Hook came out	Ittner 1982	Possibly interaction with actively fishing gear.
1983	LI	1 female pup	E, neck	Rubber ring	M	Rescued	Johanos[4]	
	Midway	1 male subadult	S	N/A	N/A	N/A	Henderson observation	
	FFS	1 female adult	E, body	Line	M	Escape	Henderson observation	Pregnant female.
		1 male pup	E, body	Net	M	Rescued	Henderson observation	Probably would have survived.
1984	FFS	1 subadult	E, neck	Plastic ring	M	No rescue	Lautenslager[4]	Probably died.
		1 male juvenile	E, neck, shoulders	Net	M	Rescued	Henderson observation	Probably would have died.
		1 female subadult	S	N/A	N/A	N/A	Elisson[4]	
		1 juvenile	S	N/A	N/A	N/A	Elisson[4]	

[1]E = entanglement, S = scarred seals.
[2]Mobile = seal bearing piece of debris; immobile = seal trapped in pile of debris.
[3]If sex unspecified, sex not known.
[4]Personal communication.
[5]All pups are weaned pups.

tality rates, parameters which must be determined to estimate the total number of seals which could potentially have been entangled from 1974 to 1984. Nevertheless, because each haul-out location supports a relatively discrete population (Johnson and Kridler 1983), minimum entanglement rates at certain islands can be approximated. Furthermore, because interisland movement is not common, island-specific entanglement rates are more important in assessing impact of entanglement on the Hawaiian monk seal.

The seal population at Lisianski Island in 1982 was 215 animals other than pups (Stone 1984). Of this total, three (1%) were entangled in 1982. The number of pups surviving to weaning at Lisianski in 1982 was 26 (Henderson 1984). Of this total, seven (27%) were entangled, four entangled in fishing debris (Henderson 1984), and three caught by plastic and other flotsam.

On Laysan Island, 28 pups survived to weaning in 1982 (Alcorn 1984), of which 2 (7%) became entangled in flotsam the same year. The subadult entangled on Laysan in 1982 represents <1% of the nonpup population there.

The observed incidents suggest that weaned monk seal pups are more likely to become entangled than are other age classes. Of the 27 entanglements observed, 11 (41%) involved weaned pups of the year, whereas pups comprise approximately 11% of the population (Gerrodette[5]). Several possible mechanisms may contribute to this disparity: (1) since pups remain near shore for 1-2 months after weaning, their entanglements, even temporary ones, are more likely to be observed; (2) the nearshore reefs serve to catch and "concentrate" floating debris, and because pups spend proportionately more time in this area, entanglements are more probable; (3) recently weaned pups are learning to feed, hence are more likely to explore all objects in their novel environment; and (4) pups are smaller and weaker than older seals and are therefore less able to escape from debris.

The large number of observed incidents in 1982 prompted the National Marine Fisheries Service and the U.S. Fish and Wildlife Service to begin gathering and burning potentially hazardous debris, and since that time the number of observed incidents has declined despite the continued presence of observers in the Northwestern Hawaiian Islands. At Lisianski Island in particular, the 10 incidents observed in 1982 have dropped to 1 in 1983 and 0 in 1984, and incidents have also diminished at Laysan Island. Removing debris from the beaches and nearshore reefs in the Northwestern Hawaiian Islands can reduce the amount of Hawaiian monk seal entanglement and remove a hazard to which weaned seal pups seem particularly susceptible.

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ENTANGLEMENT IN, AND INGESTION OF, PLASTIC LITTER BY MARINE MAMMALS, SHARKS, AND TURTLES IN NEW ZEALAND WATERS

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ABSTRACT

Since 1975 a marked increase in entanglement in, and ingestion of, plastics by marine mammals, fishes, and turtles has been observed in New Zealand. Plastic litter has increased with the development of nearshore fisheries, especially in the subantarctic, and polypropylene strapping can now be found on beaches the length of the country. New Zealand fur seal, Arctocephalus forsteri, is now frequently reported with bands about its neck. Whales and seals have been observed entangled in discarded fishing gear. Leatherback turtles and a juvenile minke whale have been observed to have ingested polythene bags at sea before becoming stranded.

The increasing use of polypropylene strapping suggests that fur seals will continue to be regularly entangled in this nondegrading litter.

INTRODUCTION

The presence of plastic and synthetic debris in the oceans of the world has become of increasing concern to marine scientists and ecologists. Plastics of many kinds are now acknowledged to be marine contaminants of global significance (Gregory et al. 1983), and, while they are especially common in the vicinity of highly populated, industrialized coastal areas (Morris 1980; Gregory et al. 1983), plastics pollution is also a feature of remote areas. Attention has been drawn to the widespread distribution of virgin plastic granules in surface waters of the major oceans of the world. A number of studies of the feeding habits of oceanic seabirds such as prions, petrels, and shearwaters has revealed that these birds, which feed on small buoyant organisms taken at the sea surface, ingest floating plastic pellets and expanded polystyrene granules along with normal prey items (Bourne and Imber 1982; Furness 1983).

The other more visible synthetic pollutants found along shores and adrift are normally the result of garbage disposal from ships at sea. Wehle and Coleman (1983) state "...that commercial fishing fleets alone dumped more that 52 million pounds of plastic packaging material into the

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

sea and lost approximately 298 million pounds of plastic fishing gear including nets, lines, and buoys."

In the New Zealand region the expansion of commercial fishing over the last decade in coastal and distant waters within the 200-mile exclusive economic zone (EEZ) has resulted in a noticeable increase in plastic and other synthetic litter such as buoys, cordage, sheet plastic, fishing net, plastic strapping, and domestic rubbish along the shores of mainland New Zealand (Ridgway and Glasby 1984) and particularly the subantarctic islands. Of all this litter one item stands out: polypropylene strapping of the sort used to secure crates, bales of netting, frozen bait, and other items is now ubiquitous on shores the length of New Zealand and throughout the subantarctic islands. In this report data are presented on the entanglement in, and ingestion of, plastic debris by marine mammals, reptiles, and fishes within the New Zealand region and the materials involved.

METHODS

Incidental observations of marine mammals and other animals involved with synthetic debris have been gathered during the course of routine data collection at marine mammal strandings, fur seal haul-out sites, and coastal fishing ports (Table 1, Fig. 1). Where possible live animals with collars or ligatures around their necks and bodies are captured, the offending material removed, and the animal released.

PINNIPEDS

Plastic Strapping

Reports of otariid seals being found in the wild with collars around their necks have been increasing in recent years. Mostly these have referred to northern fur seals and Steller sea lions in the Bering Sea and on the adjacent coasts, but examples have been reported of collars on Cape fur seals from southern Africa and Antarctic fur seals from South Georgia (Bonner and McCann 1982). The first record of an entangled New Zealand fur seal, Arctocephalus forsteri, was made in 1975 (R. Mattlin pers. commun.), and collared animals have been sighted regularly since then.

The materials involved are primarily polypropylene strapping (46%) followed by netting and rope. Polypropylene strapping systems were first introduced in New Zealand about 1969, and this tough, buoyant material is preferred by producers of bait and ship's chandlery. The strapping is hard with an embossed surface, about 16 mm wide, 1.5 mm thick, and sharp edged. It is generally light blue and is fastened around a package either by heat sealing or with a mechanical metal crimp. It appears to be common practice at sea to slip the loop of strapping off the end of a package rather than cutting it free, and the loop is then cast overboard along with other ship's garbage.

Most of the animals found with collars around their necks are near populous haul-out sites or rookeries and can be recognized by either the vivid blue collar or their impeded movement and swollen, injured, neck tissues. Apparently juvenile fur seals play with the bands which slip over their heads, and push down as far as the shoulders, and stick against the lie of the fur.

Table 1.--Record of incidental observations on encounters of marine mammals and other animals with synthetic debris in New Zealand waters.

Incident	Species	Location	Year	Material	Entangled	Ingested
1	New Zealand fur sea	Open Bay Island	1975	Polypropylene strapping	X	
2	Southern minke whale	Palliser Bay	1976	Polythene bag		X
3	New Zealand fur seal	Cape Palliser	1978	Polypropylene strapping	X	
4	New Zealand fur seal	Campbell Island	1979	Netting	X	
5	Killer whale	Bay of Plenty	1979	Rope and floats	X	
6	Rig	Porirua Harbor	1979	Plastic tag	X	
7	Leatherback turtle	Whakatane	1980	Polythene bag		X
8	New Zealand fur seal	Wanganui	1980	Polypropylene strapping	X	
9	New Zealand fur seal	Cape Palliser	1980	Polypropylene strapping	X	
10	Hooker's sea lion	Auckland Island	1981	Net	X	
11	New Zealand fur seal	At sea lat. 42°30'S long. 178°08'E	1982	Net	X	
12	New Zealand fur seal	Wellington	1982	Rope	X	
13	New Zealand fur seal	Stewart Island	1983	Polypropylene strapping	X	
14	New Zealand fur seal	Palliser Bay	1984	Polypropylene strapping	X	
15	Southern right whale	Christchurch	1984	Rope and floats	X	

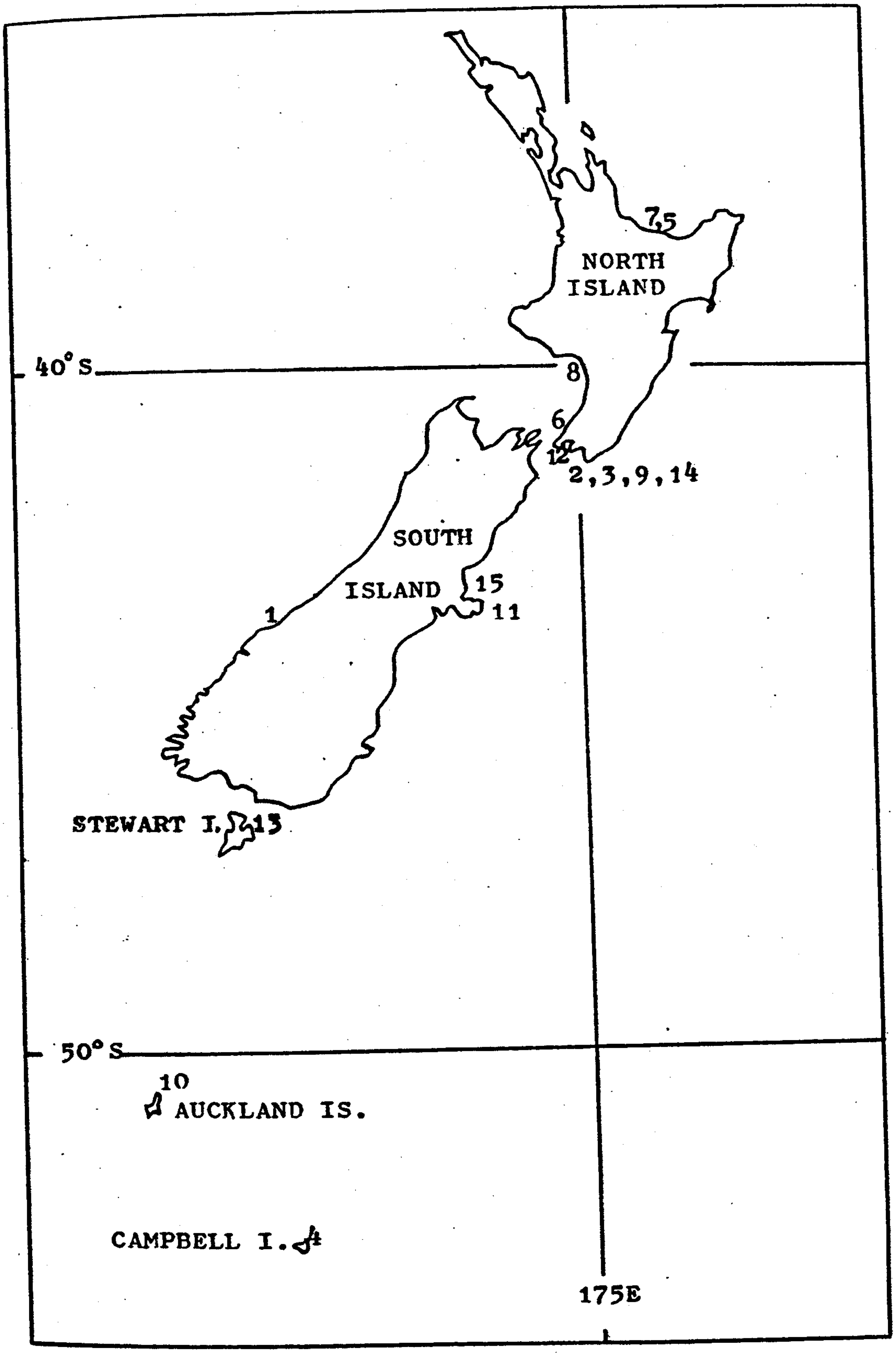

Figure 1.--Locations of incidental observations on encounters of marine mammals and other animals with synthetic debris in New Zealand waters.

As the juvenile grows the neck swells within the ligature, and the sharp-edged plastic cuts through the epidermis into the neck musculature. In four of the six observed cases of plastic collars on fur seals, wounds were raw, suppurating and swollen, and the animals lean or emaciated. One fur seal only was observed with a rope collar. The animal was a juvenile and although the collar was firmly fixed just forward of the shoulders the seal appeared in good condition. In the austral summer of 1974-75, a female fur seal was observed at Open Bay Island, South Westland, collared with blue plastic strapping and trailing a free end of the material about 3 m behind.

There have been isolated unverified reports to fishery officers of fur seals off the west coast of the South Island being sighted wearing carefully constructed rope or strapping harnesses. Locally important trawl fisheries exist in the area, and fur seals have apparently become acclimated to vessels. In 1981, a subadult male fur seal boarded the government RV James Cook at sea by climbing up the stern ramp while the vessel was trawling. The fur seal spent about 1 h aboard before leaving the ship down the stern ramp--the way it had come aboard. It has been suggested that animals such as this could have been captured, harnessed, and kept aboard vessels before they escaped back to sea.

Netting

There have been three observations of otariid seals entangled in discarded fishing net. All of these were sighted in areas where important trawl fisheries exist. In 1979 a large male fur seal was observed at sea off Campbell Island (lat. 52°33'S, long. 169°13'E) with about 1.5 m of net entangled around it neck and the upper right foreflipper. The animal appeared to be in good condition with no visible wounds, and its movements did not appear to be impeded.

Since 1978 a trawl squid fishery has developed near the Auckland Islands (lat. 50°52'S, long. 166°05'E). The Auckland Islands are the center of distribution of New Zealand's indigenous sea lion, Hooker's sea lion, Phocarctos hookeri. In 1981 a juvenile male Hooker's sea lion was observed onshore with a piece of discarded netting about 1 m long about its neck. The net collar was not tight, and it appeared the animal would have little difficulty shaking it off. Pups at the sea lion rookeries in the Auckland Islands are often observed playing with fragments of rope and other man-made materials.

During a voyage from Bluff to Wellington the MS Union Lyttelton reported a fur seal about 50 nmi east of Banks Peninsula, "caught in a fragment of fishing net. The seal dived as the vessel approached."

The entanglement of pinnipeds in netting in areas of intensive fishing is a widespread problem and has been reported by Waldichuck (1978) Shaughnessy (1980), Fowler (1982), and Wehle and Coleman (1983). Fisheries in New Zealand waters are expanding rapidly, and it is unlikely that the problem of entanglements in discarded fishing gear will be reduced in the near future.

CETACEANS

Although cetaceans have frequently become entangled in fishing gear, especially in large set trap fisheries around Newfoundland (Perkins and Beamish 1979) the absence of this type of fishery in New Zealand waters would preclude this type of entanglement. However, the extensive use of floating synthetic buoylines on rock lobster pots and deep-set nets has resulted in fouling of at least two whales in recent times (Table 1). In 1979 a killer whale, Orcinus orca, was discovered by fishermen in a distressed state entangled in ropes and floats in the eastern Bay of Plenty. How it became entangled is unknown, but fishermen believed the whale was fouled while investigating either set fishing gear, or floating debris at the surface which is frequently encountered in this area of intensive nearshore fishing.

In February 1984 a 10.45-m juvenile male southern right whale, Eubalaena australis, became stranded just north of Banks Peninsula. The whale had been reported moving slowly, north of the stranding point the day before it came ashore and was obviously in distress. It died soon after stranding and was found to have a long length of polypropylene rope, with a small polystyrene buoy attached, wrapped around its tail stock. The rope had cut 20 cm into the leading edges of both flukes. How the whale came to be entangled is unknown since no reports of damaged or lost gear were received, but the wounds were sufficiently severe to have caused the young animal considerable distress.

The only other cetacean to have died--probably as a result of plastic litter ingestion--was a juvenile minke whale, Balaenoptera acutorostrata, which became stranded in Palliser Bay, east of Wellington in 1976. The distressed juvenile had been in the area for 2 days before stranding and after repeated efforts by locals to return it to deep water it died. Necropsy revealed a compacted polythene bag stuck deep in the esophagus. Assuming the bag had been in place for some time this would account for the whale's lack of condition and thin blubber. Minke whales are known to be attracted to ships at sea and this curiosity may, in part, be responsible for their being reported eating plastic debris thrown from fishing vessels (Wehle and Coleman 1983).

Ingestion of plastic bags has been reported in other cetacean species including pigmy sperm whales, rough toothed dolphins, and Cuvier's beaked whales (Wehle 1983).

REPTILES

Marine turtles are also noted for consuming plastic bags at sea (Anonymous 1983). It is most probable that these neutrally buoyant bags are mistaken by the turtles for food items such as salps and medusae, the major food items of leatherback turtles (Wehle and Coleman 1983). Although turtles are uncommon visitors to New Zealand they are not rare. In the austral summer of 1979-80 six leatherback turtles were reported from New Zealand coastal waters. One of these became moribund and beached itself near Whakatane in the Bay of Plenty. Soon after coming ashore the turtle died and necropsy revealed the esophagus packed with polythene bread bags. Presumably the shape and color of these bags in the water are similar to those of natural prey.

FISH

Only one fish species has been reported entangled in plastic debris (Table 1). In 1979 a rig, Mustelus lenticulatus, was recovered encircled by a plastic tag of the sort used to suspend salamis and similar large sausages. The tag completely encircled the body posterior to the pectoral fins and had cut 50 mm into the dorsal fin yet the fish was not unduly disadvantaged. Sharks have been reported fouled in plastic bands and strapping (Noonan 1977; Bird 1978), but this is the first reported incidence in New Zealand of the sublethal effect of sausage tags on elasmobranchs.

CONCLUSIONS

The longevity of plastics in the marine environment is not known. The general characteristics which make synthetics so useful, namely light weight, strength, durability, flexibility, and buoyancy, contribute to most of the problems encountered by marine animals. The desirability of polypropylene strapping is likely to increase and with it the potential for continued entanglement of seals. When one animal dies as a result of a synthetic collar, that collar ultimately becomes available to yet another animal to play with and become entangled in.

In New Zealand requests have been made to bait producers and packers to print a notice on the bands that they should be severed rather than slipped off a package. The plastics manufacturers will be urged to incorporate photooxidants into their products to ensure that such materials as plastics and polypropylene strapping do not recycle. Regulations governing litter disposal at sea must be tightened, and the general public must be made aware of the dangers of these near indestructible, yet so useful materials.

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INGESTION OF PLASTIC POLLUTANTS BY MARINE BIRDS

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ABSTRACT

To date, ingestion of plastic pollutants has been recorded in 50 species of marine birds from around the world. Procellariiform birds ingest plastic most frequently, and phalaropes and some alcids also have relatively high rates of ingestion. Penguins, pelecaniform birds, larids, and most alcids ingest little or no plastic. Species feeding primarily by surface-seizing or pursuit-diving have the highest frequencies of plastic ingestion. Species feeding primarily on crustaceans or cephalopods have the highest frequencies of plastic ingestion; secondary ingestion of plastics via fish appears to be unimportant. Although some species ingest plastic randomly, most exhibit selective preferences for certain types of plastic. Monomorphic seabird species show no sexual differences in rates of plastic ingestion. Subadult seabirds ingest more pieces of plastic than do adult seabirds. Geographic and seasonal variations in plastic ingestion have been recorded. Plastic ingestion has increased since it began in the early 1960's. Limited detrimental effects of ingested plastic on the physical condition of seabirds have been documented, although red phalaropes, Laysan albatrosses, and northern fulmars show evidence of some physical impairment and parakeet auklets show evidence of decreased reproductive performance.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

INTRODUCTION

The presence of plastic pollution in marine waters was first recorded from marine birds in the northwestern Atlantic Ocean in 1962 (Rothstein 1973). Since then, a series of papers on plastic pollutants in the ocean has reported on the qualitative and quantitative distributions of floating plastic (Carpenter et al. 1972; Carpenter and Smith 1972; Cundell 1973; Kartar et al. 1973; Venrick et al. 1973; Colton et al. 1974; Hays and Cormons 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory 1977, 1978, 1983; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1982; Merrell 1980; Morris 1980a, 1980b; Van Dolah et al. 1980), the occurrence of plastic in the benthos (Kartar et al. 1973, 1976; Hays and Cormons 1974; Morris and Hamilton 1974; Jewett 1976; Feder et al. 1978), and the mechanisms that disperse or concentrate plastic and other marine pollutants (Colton et al. 1974; Wong et al. 1974, 1976; Shaw and Mapes 1979; Van Dolah et al. 1980).

Although most of the early work documented the distribution and abundance of plastic pollution at sea, it is clear that plastic pollutants were entering food webs quite soon after their appearance in the oceans (Kenyon and Kridler 1969; Rothstein 1973). A survey of work in the last decade, however, shows that the ingestion of plastic pollutants by marine birds is being recorded with greater frequency and that our impression of the problem is changing from one of a series of interesting observations to recognition of a pollution problem facing seabirds worldwide (Coleman and Wehle 1984). Concern over this problem culminated in a recent study by the senior author (Day 1980) of the dynamics of plastic pollution in a suite of 37 species of marine birds in Alaska, a relatively pristine environment remote from source areas of plastic. In that study, plastic was recorded in 15 (40.5%) of the 37 species and 448 (22.8%) of the 1,968 birds examined, illustrating how extensive plastic pollution had become in the 16 years since it was first recognized in seabirds.

In this paper, we attempt to synthesize all information available on global patterns of plastic ingestion in marine birds and we discuss the dynamics and characteristics of plastic pollutants ingested. The emphasis is on the North Pacific, for which the most complete data exist. We do not discuss the interactions of marine birds with gill net fisheries (i.e., Tull et al. 1972; Ainley et al. 1981; Coleman and Wehle 1983; Carter and Sealy 1984; Piatt et al. 1984; Piatt and Reddin 1984), the entanglement of marine birds in other marine debris (e.g., Gochfeld 1973; Bourne 1976; Coleman and Wehle 1984; Conant 1984), or the mortality of marine birds from oil or heavy-metal pollution (e.g., Bourne 1976; Ohlendorf et al. 1978).

RESULTS

General Aspects of Plastic Ingestion in Marine Birds

All ingested plastic found has been in the gizzards and (occasionally) proventriculi of the birds examined. Plastic has not been found in intestinal tracts or feces (Rothstein 1973; Day 1980; Pettit et al. 1981), indicating that passage through the intestines is minimal. This lack of passage is surprising, inasmuch as some particles are too small to handle for measurements (Day 1980).

Raw polyethylene pellets (= "nibs" of Colton et al. 1974) appear to be the major form of plastic ingested (Rothstein 1973; Baltz and Morejohn 1976; Day 1980; Anonymous 1981; Bourne and Imber 1982; Van Franeker 1983; M. J. Imber, Wildlife Service, Wellington, New Zealand pers. commun.). Asymmetrical fragments, generally broken from larger polyethylene pieces, are commonly eaten by marine birds (Rothstein 1973; Day 1980; Furness 1983; Van Franeker 1983), whereas polystyrene spherules and styrofoam (i.e., foamed polystyrene spherules) appear to be much less common (Hays and Cormons 1974; Connors and Smith 1982; Furness 1983; Van Franeker 1983; T. J. Dixon, Nature Conservancy Council, Aberdeen, Scotland pers. commun.) The presence of unfoamed polystyrene in marine birds was unexpected, because this synthetic material is neutrally or negatively buoyant (Hays and Cormons 1974; Morris and Hamilton 1974). Many other types and shapes of plastic have been recorded, including toys, polyethylene bottle caps, clear plastic sheets, and nylon, monofilament, and polypropylene line (Kenyon and Kridler 1969; Baltz and Morejohn 1976; Bourne 1976; Day 1980; Pettit et al. 1981; Harrison et al. 1983; Conant 1984).

Eleven recognized colors of plastic were ingested by seabirds in Alaska (Day 1980). Eighty-five percent of these colors were in the "light brown" color range (white, yellow, tan, and brown). Another 8% were in the other "light" shades (light blue, green, and red-pink), making over 93% of the total 833 particles ingested light in color or shade. The remaining 7% of the particles were dark in color or shade: black-gray and darker shades of blue, green, and red-pink.

The individual weight of 830 particles ingested by seabirds in Alaska averaged about 0.02 g for most species; this figure includes raw polyethylene pellets and variably sized asymmetrical fragments after post-ingestion wear (Day 1980). Mean volumes of individual particles from Alaska averaged 0.03-0.04 ml after post-ingestion wear. The mean dimensions of particles from seabirds in Alaska were 4.2 x 3.5 x 2.0 mm, again including some large plastic fragments. Unworn raw polyethylene pellets range from 3 to 5 mm in diameter (Carpenter and Smith 1972; Colton 1974; Colton et al. 1974; Gregory 1977, 1978, 1983; Shiber 1982) and average 0.014 g each in the Atlantic (Colton et al. 1974) and 0.026 g in New Zealand (Gregory 1978), Nova Scotia, and Bermuda (Gregory 1983).

Nearly all plastic particles ingested by seabirds float at the water's surface (Kenyon and Kridler 1969; Day 1980); the specific gravity of polyethylene, excluding air vacuoles, is about 0.9 (Carpenter 1976). The few negatively buoyant particles recorded are assumed to have been broken from larger floating objects or to contain air vacuoles, thereby decreasing their densities and allowing them to float.

Ingestion of Plastic Pollutants by Marine Birds: A Global Perspective

As of November 1984, ingestion of plastic pollutants had been recorded in 50 species of marine birds from around the world (Table 1). In this total, we do not include three bird species in which plastic has been recorded because they represent instances of secondary ingestion via predation of plastic-contaminated seabirds: bald eagle, Haliaeetus leucocephalus, preying on parakeet auklets in Alaska (Day unpubl. data),

Table 1.--List of seabird species that have been recorded ingesting plastic as of November 1984. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Scientific name
Wandering albatross	Diomedea exulans
Royal albatross	Diomedea epomophora
Black-footed albatross	Diomedea nigripes
Laysan albatross	Diomedea immutabilis
Gray-headed albatross	Diomedea chrysostoma
Northern fulmar	Fulmarus glacialis
Great-winged petrel	Pterodroma macroptera
Kerguelen petrel	Pterodroma brevirostris
Bonin petrel	Pterodroma hypoleuca
Cook's petrel	Pterodroma cookii
Blue petrel	Halobaena caerulea
Broad-billed prion	Pachyptila vittata
Salvin's prion	Pachyptila salvini
Antarctic prion	Pachyptila desolata
Fairy prion	Pachyptila turtur
Bulwer's petrel	Bulweria bulwerii
White-chinned petrel	Procellaria aequinoctialis
Parkinson's petrel	Procellaria parkinsoni
Pink-footed shearwater	Puffinis creatopus
Greater shearwater	Puffinis gravis
Sooty shearwater	Puffinis griseus
Short-tailed shearwater	Puffinis tenuirostris
Manx shearwater	Puffinis puffinis
White-faced storm-petrel	Pelagodroma marina
British storm-petrel	Hydrobates pelagicus
Leach's storm-petrel	Oceanodroma leucorhoa
Sooty storm-petrel	Oceanodroma tristrami
Fork-tailed storm-petrel	Oceanodroma furcata
Blue-footed booby	Sula nebouxii
Red-necked phalarope	Phalaropus lobatus
Red phalarope	Phalaropus fulicaria
Laughing gull	Larus atricilla
Heermann's gull	Larus heermanii
Mew gull	Larus canus
Herring gull	Larus argentatus
Western gull	Larus occidentalis
Glaucous-winged gull	Larus glaucescens
Glaucous gull	Larus hyperboreus
Great black-backed gull	Larus marinus
Black-legged kittiwake	Rissa tridactyla
Red-legged kittiwake	Rissa brevirostris
"Terns"	Sterna spp.
Dovekie	Alle alle
Thick-billed murre	Uria lomvia
Cassin's auklet	Ptychoramphus aleuticus
Parakeet auklet	Cyclorrhynchus psittacula
Least auklet	Aethia pusilla
Rhinoceros auklet	Cerorhinca monocerata
Tufted puffin	Fratercula cirrhata
Horned puffin	Fratercula corniculata

Antarctic skua, Catharacta antarctica, preying on broad-billed prions in the South Atlantic (Bourne and Imber 1982), and short-eared owl, Asio flammeus, preying on blue-footed boobies in the Galápagos Islands (Anonymous 1981). We also omit the Antarctic fulmar, Fulmarus glacialoides, and the Atlantic puffin, Fratercula arctica, which have been reported to ingest elastic threads but not plastic (Parslow and Jefferies 1972; Crockett and Reed 1976). In addition, great frigatebird, Fregata minor, may pick up pieces of marine debris, but do not appear to ingest them (Conant 1984).

All seabird species that have been examined for plastic ingestion, an their rates of ingestion, are listed in Table 2. Twenty-eight (56%) of th species ingesting plastic are procellariiform birds, 1 (2%) is a pelecaniform bird, 2 (4%) are phalaropes, 11 (22%) are gulls and terns, and 8 (16% are alcids.

The highest frequencies of plastic ingestion are recorded in procellariiform species and in the parakeet auklet, an alcid breeding in the North Pacific. The highest mean number of particles ingested, 21.7 particles per bird, was found in short-tailed shearwaters from California (Baltz and Morejohn 1976). Greater shearwaters from South Africa (Furness 1983) and parakeet auklets from Alaska (Day 1980) exhibited the second and third highest amounts of plastic ingestion, respectively. Of the 50 species containing plastic, only 12 have been recorded ingesting a mean of one or more particles per bird (Table 2).

We have summarized the data from Table 2 in terms of frequencies of ingestion in families and in groups of similar species (Table 3). To determine the approximate mean frequency of occurrence of plastic per species within a particular taxon, we: (1) estimated the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculated mean frequencies of occurrence from these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Procellariiform birds exhibit high overall rates of ingestion; 28 (90%) of 31 species examined contained plastic. This group also has a relatively high mean frequency of occurrence per species, indicating that many individuals of many species have ingested plastic. Penguins and sea ducks have not yet been recorded with plastic. Pelecaniform birds contain little or no plastic, and have a very low mean frequency of occurrence per species. Among the charadriiform birds, phalaropes and some alcids (auklets-dovekie and puffins) have both high rates of ingestion and relatively high frequencies of occurrence per species. In contrast, larid have a high overall rate of ingestion but a low frequency of occurrence pe species, indicating that only a few individuals of many species in this taxon have ingested plastic.

Effects of Feeding Ecology on Variation in Plastic Ingestion

The only analysis of the relationships between feeding ecology and plastic ingestion is from Day (1980). Twenty-six percent of the birds fro Alaska classified as primarily pursuit-divers contained plastic, the highest incidence among all feeding methods; 16% of those seabirds feeding

Table 2.--A list of all species of seabirds that have been examined for plastic ingestion and their rates of ingestion. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Wandering albatross	?	1-5	"Low"	Subantarctic (Chatham Islands)	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
	?	Present	?	South Atlantic (Gough Island)	?	From chick regurgitations.	Furness 1983.
Royal albatross	?	1-5	"Low"	Chatham Islands	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
Black-footed albatross	172	Present	?	Hawaiian Islands	1978-81	One adult died from choking on toy; broken fragments, manufactured pieces, cellophane, styrofoam, thermal underwear.	Harrison et al. 1983; M. Naughton pers. commun.
	?	Present	?	Hawaiian Islands	1981	From chick found dead; plastic bags, bottle caps, plastic fragments.	Conant 1984.
Laysan albatross	100	76	2.4	Hawaiian Islands	1966	From chicks found dead.	Kenyon and Kridler 1969.
	1	0	0	Alaska	1969-77	--	Day 1980.
	183	Present	?	Hawaiian Islands	1978-81	Plastic chips, styrofoam, monofilament line.	Harrison et al. 1983.
	4	100	?	Hawaiian Islands	1979-80	From chicks found dead; intestinal blockage, ulceration of proventriculus.	Pettit et al. 1981.
	50	90	?	Hawaiian Islands	1982-83	From chicks found dead; three chicks with plastic impaction and ulcerative lesions.	S. I. Fefer pers. commun.
	4	50	?	Hawaiian Islands	1982-83	From adults.	S. I. Fefer pers. commun.
Gray-headed albatross	?	Present	?	Subantarctic (Marion Island)	?	--	Furness 1983.
Antarctic fulmar	26	0	0	New Zealand	1973-75	Birds found dead.	Crockett and Reed 1976.
Northern fulmar	38	58	2.8	Alaska	1969-77	Both raw plastic and fragments; primarily light-colored.	Day 1980.
	36	3-33	?	Scotland	?	Nylon threads and plastic combined; some plastics causing stomach ulcerations; much other man-made debris.	Bourne 1976.
	3	100	11.3	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	214	40	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Northern fulmar	?	<10	?	Scotland/North Sea	?	Foamed polystyrene.	T. J. Dixon pers. commun.
	88	80	5	Netherlands	1981-82	From birds found dead; raw plastic, other plastic types.	Van Franeker 1983.
	29	76	4	Jan Mayen Island	1983	Also reported large nail embedded in thick layer of fatlike tissue in distal part of gut of one bird.	Van Franeker and Camphuijsen 1984.
Great-winged petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Kerguelen petrel	26	4	<0.1	New Zealand	1981	From dead birds; raw plastic.	Reed 1981.
Bonin petrel	144	Probably present	?	Hawaiian Islands	1978-81	Regurgitation; presence of plastic not confirmed.	Harrison et al. 1983; C. S. Harrison pers. commun.
Cook's petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Blue petrel	?	20	?	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	27	100	?	New Zealand	1981	From dead birds.	Reed 1981.
Broad-billed prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
	?	Present	?	Chatham Islands	?	Raw plastic.	Bourne and Imber 1982.
	?	Present	?	Gough Island	1979	Recorded in only one of a few birds examined; the one contained 33 pieces of raw plastic.	Bourne and Imber 1982.
Salvin's prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Antarctic prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Fairy prion	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Bulwer's petrel	100	Present	?	Hawaiian Islands	1978-81	Regurgitation.	Harrison et al. 1983.
White-chinned petrel	20	5	0.5	South Africa	1981	Fragments.	Furness 1983.
Parkinson's petrel	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Pink-footed shearwater	5	20-40	2.4	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Greater shearwater	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	98	40	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	?	"Low"	?	Massachusetts	1977	Regurgitations	Powers and Van Os 1979.
	2	100	22	Gough Island	1980	Primarily polyethylene; also polyolefin and nylon.	Randall et al. 1983.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	10	90	20.6	South Africa	1981	Raw plastic and polystyrene spheres.	Furness 1983.
Wedge-tailed shearwater	233	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Sooty shearwater	76	43	1.1	Alaska	1969-77	Both raw plastic and fragments; primarily light-colored.	Day 1980.
	21	43-67	6.9	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	35	17	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	37	51	?	California	1977	Both raw plastic and fragments; white, red, blue, and brown.	E. W. Chu pers. commun.
	154	49	?	California	1978-79	Both raw plastic and fragments; white, red, blue, and brown.	E. W. Chu pers. commun.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	13	0	0	South Africa	1981	--	Furness 1983.
Short-tailed shearwater	200	84	5.4	Alaska	1969-77	Both raw plastic and fragments; great diversity of colors.	Day 1980.
	6	100	21.7	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	189	47	1.0	Australia/Tasmania	1979-80	--	I. J. Skira pers. commun.
Christmas shearwater	182	0	0	Hawaiian Islands	1978-81	From regurgitations	Harrison et al. 1983.
Manx shearwater	?	Present	?	?	?	--	Van Franeker 1983.
Gray-backed storm-petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
White-faced storm-petrel	?	50	"Low-high"	Chatham Islands	?	Raw plastic.	M. J. Imber pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
British storm-petrel	?	Present	?	?	?	--	Van Franeker 1983.
Leach's storm-petrel	7	14	0.3	Eastern Canada	1962	From adults.	Rothstein 1973.
	7	57	1.0	Eastern Canada	1964	From adults.	Rothstein 1973.
	8	25	0.2	Eastern canada	1964	From chicks.	Rothstein 1973.
	4	25	3.0	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
Sooty storm-petrel	10	10	0.1	Hawaiian Islands	1978-81	From regurgitations; broken fragments.	Harrison et al. 1983; M. Naughton pers. commun.
Fork-tailed storm-petrel	8	100	6.2	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
Common diving petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Emperor penguin	?	0	0	Antarctic	?	--	M. J. Imber pers. commun.
Little blue penguin	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Red-tailed tropicbird	270	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Great frigate-bird	284	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Double-crested cormorant	4	0	0	Alaska	1969-77	--	Day 1980.
Shag	2	0	0	Scotland	?	--	Bourne 1976.
Red-faced cormorant	2	0	0	Alaska	1969-77	--	Day 1980.
Pelagic cormorant	3	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Gannet	3	0	0	Scotland	?	--	Bourne 1976.
Masked booby	305	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Blue-footed booby	?	Present	?	Galapagos Islands	?	Raw plastic; secondarily via fish.	Anonymous 1981.
Red-footed booby	360	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown booby	244	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Greater scaup	3	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Harlequin duck	6	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Oldsquaw	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Surf scoter	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
White-winged scoter	5	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Barrow's goldeneye	17	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Red-necked phalarope	3	67	1.0	Alaska	1969-77	All light-colored pieces.	Day 1980.
	2	0	0	California	1981	Northbound migrants.	Connors and Smith 1982.
Red phalarope	20	"Most"	?	California	1969	From starving birds; up to 36 particles per bird.	Bond 1971.
	4	25	0.2	California	1979	Southbound migrants.	Connors and Smith 1982.
	7	86	5.9	California	1980	Northbound migrants; primarily polyethylene; a few pieces of styrofoam.	Connors and Smith 1982.
"Skuas"	3	0	0	Scotland	?	--	Bourne 1976.
Pomarine jaeger	1	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Parasitic jaeger	1	0	0	Alaska	1969-77	--	Day 1980.
"Gulls"	?	Present	?	New York	1971	Probably herring gull.	Hays and Cormons 1974.
"Large gulls"	13	0	0	Scotland	?	--	Bourne 1976.
Laughing gull	?	Present	?	Florida	1975-78	From regurgitated casts; plastic occasionally present.	Below 1979.
Bonaparte's gull	4	0	0	Alaska	1969-77	--	Day 1980.
Heermann's gull	15	7-13	0.1	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Mew gull	10	0	0	Alaska	1969-77	--	Day 1980.
	4	25	0.3	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Germany	?	--	Vauk-Hentzelt and Schumann 1980 cited in Vauk-Hentzelt 1982.
Herring gull	?	Present	?	Germany	1967	--	Vauk and Lohmer 1969 cited in Vauk-Hentzelt 1982.
	5	0	0	Alaska	1969-77	--	Day 1980.
	?	Present	?	Maine	1979-82	Plastic bags, styrofoam, cellophane.	D. H. S. Wehle pers. observ.
Western gull	?	Present	?	North Pacific	?	--	H. Ogi pers. commun.
Glaucous-winged gull	63	0	0	Alaska	1969-77	--	Day 1980.
	8	13	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Alaska	1984	Small plastic toy in regurgitated cast, western Aleutian Islands.	R. S. Wood and A. W. DeGange pers. commun.
Glaucous gull	33	3	0.0	Alaska	1969-77	--	Day 1980.
Great black-backed gull	?	Present	?	Maine	1979-82	Plastic bags, styrofoam cellophane.	D. H. S. Wehle pers. observ.
Black-legged kittiwake	188	5	0.1	Alaska	1969-77	Primarily broken fragments; light-colored.	Day 1980.
	8	13-25	0.5	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	50	12	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
	28	4-7	?	Scotland	?	Nylon threads and plastic	Bourne 1976.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Red-legged kittiwake	46	13	0.2	Alaska	1969-77	Raw plastic; primarily light-colored.	Day 1980.
Sabine's gull	1	0	0	Alaska	1969-77	--	Day 1980.
Ivory gull	1	0	0	Alaska	1969-77	--	Day 1980.
"Terns"	?	"A few"	?	New York	1971	Regurgitated casts; common and roseate terns breed here.	Hays and Cormons 1974.
Arctic tern	21	0	0	Alaska	1969-77	--	Day 1980.
Aleutian tern	8	0	0	Alaska	1969-77	--	Day 1980.
Gray-backed tern	272	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Sooty tern	356	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown noddy	354	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Black noddy	494	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Blue-gray noddy	111	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
White tern	241	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
"Auks"	37	3-5	?	Scotland	?	Nylon threads and plastic combined.	Bourne 1976.
Dovekie	303	Present	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
	?	4	?	North Atlantic	?	--	Van Franeker 1983.
Common murre	191	0	0	Alaska	1969-77	--	Day 1980.
Thick-billed murre	138	1	0.0	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	283	1	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
Pigeon guillemot	18	0	0	Alaska	1969-77	--	Day 1980.
Marbled murrelet	61	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Kittlitz' murrelet	5	0	0	Alaska	1969-77	--	Day 1980.
Ancient murrelet	16	0	0	Alaska	1969-77	--	Day 1980.
Cassin's auklet	10	40	3.8	Alaska	1969-77	Both raw plastic and fragments; light-colored; very small pieces.	Day 1980.
Parakeet auklet	?	Present	?	Alaska	?	Raw plastic; light-colored.	Olhendorf et al. 1978.
	116	75	13.7	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	1	100	8	Hawaiian Islands	1980	Found dead; all particles black.	Pettit et al. 1981.
Least auklet	89	1	0.0	Alaska	1969-77	--	Day 1980.
Whiskered auklet	5	0	0	Alaska	1969-77	--	Day 1980.
Crested auklet	85	0	0	Alaska	1969-77	--	Day 1980.
Rhinoceros auklet	20	0	0	Alaska	1969-77	--	Day 1980.
	26	4	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
Tufted puffin	348	15	0.5	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.
Atlantic puffin	6	0	0	United Kingdom	1969-71	Birds found dead; elastic threads, but no plastic.	Parslow and Jefferies 1972.
Horned puffin	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
	148	37	0.9	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.

Table 3.--Rates of plastic ingestion in families of birds and in groups of similar species, calculated from the data in Table 2. The approximate mean frequency of occurrence of plastic per species was calculated by: (1) estimating the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculating a mean frequency of occurrence for these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Taxon	No. of species examined for plastic in taxon	Frequency of occurrence of plastic in taxon (%)	Approximate mean frequency of occurrence of plastic per species (%)
PROCELLARIIFORMES			
Diomedeidae	5	100	28
Procellariidae	21	86	24
Gadfly petrels	4	100	8
Prions	4	100	40
Shearwaters-fulmars	9	67	31
Other	4	100	32
Hydrobatidae	6	83	38
Pelecanoididae	1	0	0
SPHENISCIFORMES			
Spheniscidae	2	0	0
PELECANIFORMES			
Phaethontidae	1	0	0
Fregatidae	1	0	0
Phalacrocoracidae	4	0	0
Sulidae	5	20	? (low)
ANSERIFORMES			
Anatidae	6	0	0
CHARADRIIFORMES			
Scolopacidae (phalaropes)	2	100	45
Laridae	≥26	≤47	≤3
Skuas-jaegers	3	0	0
Gulls	14	71	6
Terns	≥9	≤11	? (very low)
Alcidae	≥16	≤50	≤11
Murres-guillemots-murrelets	≥6	≤17	<1
Auklets-dovekie	6	67	18
Puffins	4	75	14

by surface-seizing, 9% of those feeding by dipping, and none of those feeding by plunging or piracy contained plastic (Table 4). Some bias is present in these results, however, because shearwaters, which were classified as primarily pursuit-divers, also feed extensively by surface-seizing. If the data for shearwaters are combined with those for surface-seizers, as many as 52% of the surface-seizers and as few as 16% of the pursuit-divers contained plastic. This bias notwithstanding, a significant number of species previously considered to be exclusively subsurface-feeding contained plastic found only at the surface of the water, suggesting that many pursuit-divers exhibit a greater range of feeding behaviors than was believed previously.

Table 4.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary feeding method (from Day 1980). Feeding method classifications are from Ashmole (1971) and Day (1980).

Feeding method	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Pursuit-diving	1,532	399	26.0
Surface-seizing	157	25	15.9
Dipping	256	24	9.4
Plunging	21	0	0
Piracy	2	0	0

Birds feeding by plunging or piracy show no evidence of plastic ingestion. Plungers generally sight individual prey items below the surface of the water (Ashmole 1971), where floating plastic is not found, and they probably cannot distinguish objects as small as plastic particles from the air. Those birds feeding by piracy take food dropped by other birds; such food is primarily fish (Ashmole 1971) and appears to contain little or no plastic.

Birds feeding by hydroplaning, a method not used by Alaska's seabirds, also exhibit high rates of plastic ingestion (Tables 2 and 3). The prions use this method to filter surface water, where the plastic occurs, through their bill lamellae (Ashmole 1971). Approximately 50% of the prions examined by M. J. Imber (pers. commun.) contained plastic (Table 2).

Another feeding method, scavenging at the sea's surface, is used to varying degrees by seabirds throughout the world (Ashmole 1971). Unfortunately, its importance relative to other feeding methods is often difficult to quantify. Scavenging is common in many procellariiform birds and in gulls (Ashmole 1971); interspecies variation in degree of scavenging probably accounts for some of the variation in ingestion frequencies seen in these groups.

Plastic ingestion also can be correlated with a given species' preferred prey (Table 5). Generally, those species of seabirds from Alaska relying primarily on crustaceans or cephalopods had a higher frequency of plastic ingestion than did those relying primarily on fishes (Day 1980): species feeding primarily on crustaceans had a significantly higher frequency of ingestion than did fish-feeders ($\chi^2 = 305.6$; 1 df; $P < 0.001$; chi-square R x C test; Conover 1971), as did cephalopod-feeders when compared with fish-feeders ($\chi^2 = 68.2$; 1 df; $P < 0.001$). Thus, secondary ingestion of plastic via fish is evidently low, although it has been proposed for blue-footed boobies in the Galapagos Islands (Anonymous 1981). Cephalopod- and crustacean-feeding seabirds showed no significant difference in the frequency of plastic ingestion ($\chi^2 = 1.1$; 1 df; $P > 0.05$), indicating that both were important in effecting plastic ingestion.

Table 5.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary prey type (adapted from Day 1980). Prey type classifications are from Ashmole (1971) and Day (1980).

Prey type	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Crustaceans	566	270	47.8
Cephalopods	39	22	56.4
Fishes	1,363	156	11.4

Prey type was a better predictor of plastic occurrence in seabirds than was feeding method, probably because of the particles' similarities (location in the water column and in physical attributes) to known and probable prey items. A number of known and probable prey items occur regularly in surface waters, where plastic might be mistaken for, or ingested, along with these prey. In Alaska, squid larvae live primarily within the upper 0.5 m of the sea's surface; in addition, the adults undergo a circadian pattern of vertical migration and are found at the sea's surface at night (Clarke 1966; C. G. Bublitz, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). The planktonic larvae and adults of many pelagic crustaceans (e.g., copepods, euphausiids), which many of the light-brown particles of raw plastic eaten by seabirds resemble (Table 2), are also found at or near the water's surface (Mauchline 1980; Raymont 1983).

The eggs of many fishes are also found at the surface of the ocean (Hart 1973). These pelagic eggs are rarely recorded in seabirds, probably because they are rapidly digested in the birds' stomachs. Flyingfish (Exocoetidae) eggs attached to plastic have been found in Laysan and black-footed albatrosses (Pettit et al. 1981; Harrison et al. 1983), and some sea ducks and gulls eat the benthic eggs of some nearshore fishes (Outram 1958; Gjosaeter and Saetre 1974). Colton (1974) originally mistook the light-brown pellets of raw plastic that he had caught in neuston tows for pelagic fish eggs, and several scientists at the University of Alaska mistook the samples of Day (1980) for fish eggs. The small, round pellets could also be mistaken by the birds for the eyes of squids or fishes or for the bodies of larval fishes. Thus, it is not surprising that those seabirds feeding primarily on crustaceans or cephalopods exhibit a higher occurrence of plastic than do those species feeding primarily on fish.

Interspecific Variation in Plastic Ingestion

An obvious question to be asked is whether seabirds actively select specific kinds of plastic or randomly eat any plastic that they encounter at sea. Examination of two data sets from the North Pacific suggests that the former hypothesis is correct.

Table 6 compares the numbers and frequencies of colors of 833 plastic particles ingested by Alaska seabirds (Day 1980) with numbers and frequencies of colors of 250 pieces of floating plastic sighted from the deck of a ship during a cruise in the subtropical North Pacific from Honolulu, Hawaii, to Hakodate, Japan, between 10 and 22 August 1984 (Dahlberg and Day 1985; Day unpubl. data).

We make two assumptions about this latter data set: (1) We assume that the frequencies of plastic colors in the subtropical North Pacific are representative of the frequencies of colors of plastic in the subarctic North Pacific, where the seabirds were collected; and (2) since about 73% of the plastic particles ingested by these seabirds are raw polyethylene pellets rather than plastic fragments, we assume that the frequencies of raw polyethylene pellets in the ocean are reflected in the frequencies of colors of these larger plastic objects. We see no reason why there should be geographic variation in frequencies of colors of plastic in the ocean; Dahlberg and Day (1985) found no geographic variation in frequencies of types of marine debris. No data are available for determining the accuracy of the second assumption.

There is a significant difference between frequencies of colors of plastic objects in the stomachs of seabirds from Alaska and frequencies of colors of floating plastic objects (X^2 = 1,280.4; 7 df; $P < 0.001$; chi-square goodness-of-fit test; Zar 1984). In this test, we omitted the color columns "orange" and "transparent" (Table 6), since they could not be adequately compared; although both colors were recorded in short-tailed shearwaters, they were not recorded in subsamples examined. Hence, the adjusted sample size for the subtropical North Pacific is 229. White, yellow, and blue occurred significantly less frequently in the birds than they did in the ocean (partial chi-square value for cells = 214.5, 21.8, and 34.5, respectively), whereas tan and brown occurred more frequently in birds than they did in the ocean (partial chi-square value for cells = 78.9 and 225.6, respectively). Yellow, brown, blue, red, green, and black-gray did not occur in proportions significantly different from that in the ocean (partial chi-square values for each cell did not exceed 1.9), suggesting that seabirds randomly ingest particles of these colors. There was some selection for the "light brown" colors (white, yellow, tan, brown; see following paragraph) as a group, however, for they constituted 79.0% of the plastic in the ocean but formed 85.0% of the plastic in the birds' stomachs.

Table 6.--Numbers and percentages of colors of plastic ingested by seabirds in Alaska (from Day 1980) and numbers and percentages of colors of floating plastic objects recorded in the subtropical North Pacific, 10-22 August 1984 (Day unpubl. data). Chi-square contributions are for deviations from expected values, which are calculated from frequencies seen in the North Pacific; total chi-square from goodness-of-fit test = 1,280.4 (7 df; Zar 1984).

	Sample size (n)	Color[1]							
		White	Yellow	Tan	Brown	Blue	Red	Green	Black-gray
Alaska seabirds	833	152	6	459	92	40	20	40	24
Frequency (%)		18.2	0.7	55.1	11.0	4.8	2.4	4.8	2.9
Expected values[2]		469.2	32.7	134.6	21.8	98.2	18.2	40.0	18.2
χ^2 contribution[3]		214.5	21.8	781.9	225.6	34.5	0.2	0.0	1.9
Subtropical North Pacific	229	129	9	37	6	27	5	11	5
Frequency (%)		56.3	3.9	16.2	2.6	11.8	2.2	4.8	2.2

[1]The colors orange and transparent were recorded in the North Pacific (n = 15 and n = 6, respectively) and in Alaska seabirds (short-tailed shearwaters; Day pers. observ.), but not in subsamples of plastic examined. Because no estimates of frequencies in seabirds were available for these two colors, they were omitted from the table and the test.

[2]Expected number of particles in each color category, based on the frequency of each color in the environment (i.e., the North Pacific).

[3]Chi-squared for P = 0.05 is 14.067; for P = 0.01 is 18.475; for P = 0.001 is 24.322 (all for 7 df).

An analysis of color-shape combinations of plastic particles ingested by seabirds from Alaska (Day 1980) also provides evidence of selective ingestion. To determine preferences for certain combinations of colors and shapes of particles, the particles ingested by each species were classified into four color-shape categories ("light brown-regular," "light brown-irregular," "other color-regular," and "other color-irregular"), and deviations of frequencies of each particle type from the combined frequencies of all species were determined with a chi-square test for independence (Zar 1984). "Light brown" colors, which resemble the colors of many natural prey items, were white, yellow, tan, and brown, and the "other" color category included the remaining colors. "Regular" shapes were pill, cylinder, sphere, and box-cube (as classified in Day 1980). All regularly shaped particles were roughly similar in size and shape, in contrast to the highly variable "irregular" particles.

The total X^2 of 108.3 shows a significant dependence between the species of seabird and the type of plastic eaten (Table 7). Only sooty shearwaters, short-tailed shearwaters, and tufted puffins appeared to ingest plastic at random, whereas the others showed strong affinities for or avoidances of certain color-shape combinations. The parakeet auklet, which feeds primarily on zooplanktonic crustaceans (Bedard 1969), was the most extreme in preferences: 94% of its plastic were in the light brown-regular category. These preferences support the hypothesis that at least some species mistake many particles for food items.

Other evidence for selective ingestion comes from the extreme interspecific variation in ingestion frequencies seen in Table 2. Also, some seabirds (e.g., Leach's storm-petrel, fork-tailed storm-petrel, Cassin's auklet) selectively ingest very small plastic particles (Day 1980), indicating selectivity for size of particles rather than for color or shape. Hence, although some species may ingest plastic randomly, most are quite specific in the types of plastic that they eat.

Sex and Age-Related Variation in Plastic Ingestion

No significant differences in the number of plastic particles ingested were found between sexes in any of the six seabird species examined from Alaska (Table 8). This observation compares well with data on feeding habits of monomorphic seabird species (most have monomorphic bills), in which there is almost 100% overlap in intersexual food habits (Tuck 1960; Bedard 1969; Sealy 1975; Wehle 1982).

Significantly more plastic particles were found in subadult parakeet auklets and tufted puffins from Alaska than in adults (Table 8). No significant differences between subadult and adult horned puffins were found, although the relatively small sample size of subadults may have affected the validity of the statistical test. Age-related differences in food habits have been found in ancient murrelets (Sealy 1975) and tufted and horned puffins (Wehle 1982), but not in marbled murrelets (Sealy 1975).

Subadult birds of many species are less efficient at foraging than are adults (Orians 1969; Recher and Recher 1969; Dunn 1972; Morrison et al. 1978; Searcy 1978). Hence, there should be selective pressures on subadults to compensate for poorer foraging efficiency by broadening their feeding niches, possibly increasing the amount of nonfood items eaten. The

Table 7.--Numbers and percentages of color-shape combinations of plastic particles ingested by six seabird species in Alaska (data reanalyzed from Day 1980). Also included are chi-square values for deviations from expectation, using a chi-square R x C test for independence (Zar 1984); total χ^2 of 108.3 shows a significant ($P < 0.001$; df = 15) dependence between the species of seabird and the type of plastic eaten.

	Sample size (n)	"Light brown" colors[1]		"Other" colors[1]		Total species χ^2 value
		"Regular" shapes[2]	"Irregular" shapes[2]	"Regular" shapes	"Irregular" shapes	
Northern fulmar	97	56	34	3	4	
Frequency (%)		57.8	35.1	3.0	4.1	
χ^2 contribution[3]		2.6	29.6	0.9	2.5	35.6
Sooty shearwater	77	50	10	6	11	
Frequency (%)		64.9	13.0	7.8	14.3	
χ^2 contribution		0.5	0.1	0.9	2.6	4.1
Short-tailed shearwater	164	114	24	10	16	
Frequency (%)		69.5	14.6	6.1	19.8	
χ^2 contribution		0.1	0.0	0.2	0.2	0.5
Parakeet auklet	120	113	0	4	3	
Frequency (%)		94.2	0	3.3	2.5	
χ^2 contribution		8.6	17.1	1.0	5.4	32.1
Tufted puffin	139	117	10	6	6	
Frequency (%)		84.2	7.2	4.3	4.3	
χ^2 contribution		3.1	4.9	0.3	3.2	11.5
Horned puffin	127	68	25	10	24	
Frequency (%)		53.5	19.7	7.9	18.9	
χ^2 contribution		5.8	2.6	1.5	14.6	24.5
Combined total	724	518	103	39	64	108.3
Frequency (%)		71.5	14.2	5.4	8.8	

[1]"Light brown" = white, tan, yellow, brown; "other" = dark blue, medium-light blue, dark red, medium-light red, dark green, medium-light green, black-gray.

[2]"Regular" = pill, cylinder, sphere, box-cube; "irregular" = string, cone, asymmetrical, other.

[3]Chi-squared for P = 0.005 is 24.996; for P = 0.01 is 30.578; for P = 0.001 is 32.801 (all for 15 df).

Table 8.--Results of tests for sexual (A) and age-related (B) differences in the number of plastic particles ingested by Alaska seabirds (from Day 1980). Parakeet auklets were tested with a Mann-Whitney test; all other species were tested with a median test (Conover 1971).

Species	Sample sizes (n)[1]	df	Test statistic	Significance
(A) Male versus female (all two-tailed tests)				
Northern fulmar	17/12	1	1.129	NS[2]
Sooty shearwater	37/26	1	1.397	NS
Short-tailed shearwater	101/73	1	0.590	NS
Parakeet auklet	49/36	1	[3]1,034.5	NS
Tufted puffin	43/38	1	0.294	NS
Horned puffin	23/45	1	0.008	NS
(B) Adult versus immature (all one-tailed tests)				
Parakeet auklet	32/10	1	[4]231.5	$0.01<P<0.05$
Tufted puffin	81/17	1	17.080	$P<0.001$
Horned puffin	68/8	1	0.349	NS

[1]Sample sizes for the two classes tested are separated by a slash.

[2]NS = not significant at $\alpha = 0.05$.

[3]$W_{0.95} = 1,067.0$.

[4]$W_{0.95} = 2.5.7$; $W_{0.99} = 238.7$.

increased amount of plastic ingested by subadults also may be due to a poorer perception of what constitutes a "good" food item, or to the possibility that subadults naturally ingest a wide range of food items to learn differences among them.

Geographic Variation in Plastic Ingestion

Day (1980) analyzed geographic variation in plastic ingestion in seabirds from Alaska, dividing the marine waters of the state into three regions: the Gulf of Alaska, the Aleutian Islands, and the Bering and Chukchi Seas (Fig. 1). Five species of birds provided reasonable sample sizes from each of these three regions. Two of these species (black-legged kittiwake and thick-billed murre) had frequencies of plastic ingestion too low for meaningful intraspecies comparisons, and thus, were not tested. In the remaining three species (parakeet auklet, tufted puffin, and horned puffin), the highest frequencies of ingestion and mean numbers of particles per bird occurred in Aleutian Islands waters (Table 9; chi-square R x C test; Conover 1971).

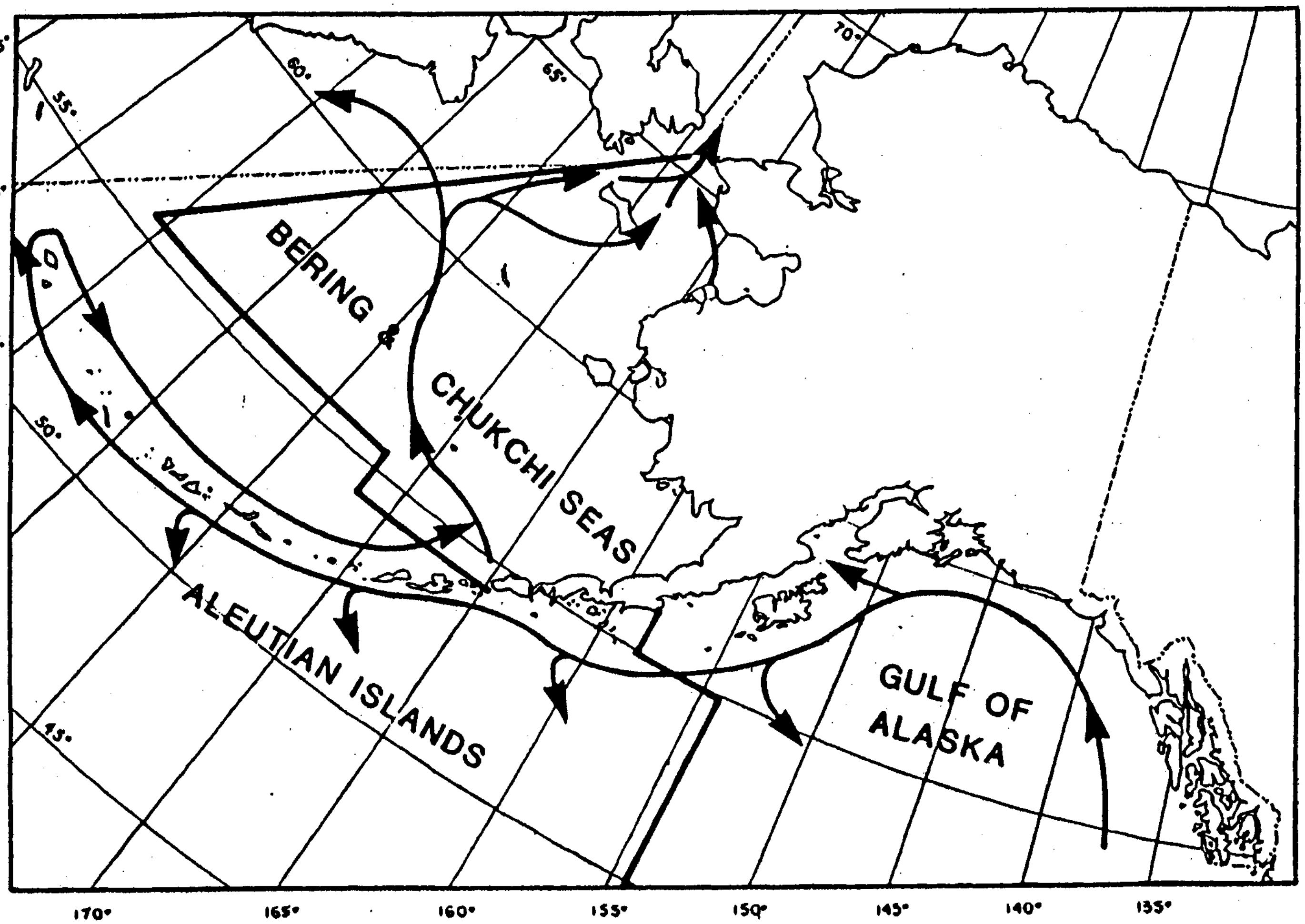

Figure 1.--Location of three geographic regions of Alaska in which differences in rates of plastic ingestion were tested (from Day 1980). The approximate locations of major currents are adapted from Coachman et al. (1975), Tabata (1975), Favorite et al. (1976), and T. C. Royer (pers. commun.).

Table 9.--Geographic variation in the frequency of occurrence of plastic (A) and in the mean number of plastic particles per bird (B) in the parakeet auklet, tufted puffin, and horned puffin in Alaska (from Day 1980).

(A) Frequency of occurrence of plastic

Species	Gulf of Alaska			Aleutian Islands			Bering and Chukchi Seas		
	(n)	No. with plastic	Frequency (%)	(n)	No. with plastic	Frequency (%)	(n)	No. with plastic	Frequency (%)
Parakeet auklet	13	11	84.6	55	50	90.9	45	24	53.3
Tufted puffin	190	20	10.5	122	35	20.5	35	5	14.3
Horned puffin	41	11	26.8	74	37	50.0	20	6	30.0

(B) Mean number of plastic particles per bird

Species	Gulf of Alaska		Aleutian Islands		Bering and Chukchi Seas	
	(n)	Mean $\pm$ SD	(n)	Mean $\pm$ SD	(n)	Mean $\pm$ SD
Parakeet auklet	14	21.1 $\pm$ 22.6	55	21.3 $\pm$ 22.8	46	2.6 $\pm$ 4.0
Tufted puffin	190	0.2 $\pm$ 0.8	122	0.7 $\pm$ 2.1	36	0.6 $\pm$ 2.9
Horned puffin	41	0.8 $\pm$ 1.7	87	1.0 $\pm$ 1.5	20	0.6 $\pm$ 1.2

Parakeet auklets in the Gulf of Alaska ($X^2 = 4.3$; 1 df; $P < 0.05$) and the Aleutian Islands ($X^2 = 18.1$; 1 df; $P < 0.001$) had higher frequencies of plastic ingestion than did birds in the Bering and Chukchi Seas. No significant difference in frequencies was found between birds in the Gulf of Alaska and the Aleutian Islands, although one of the expected values was too small for valid statistical testing.

Horned puffins in the Aleutian Islands had a higher frequency of plastic ingestion than did birds in the Gulf of Alaska ($X^2 = 5.9$; 1 df; $P < 0.05$); significant differences were not found in any other test for this species. Tufted puffins from the Aleutian Islands had a higher frequency of plastic ingestion than did birds from the Gulf of Alaska ($X^2 = 5.9$; 1 df; $P < 0.05$), but no other significant differences were found for this species.

When the combined data for all birds of all species ingesting plastic were tested among the three regions, a similar pattern emerged. A Kruskal-Wallis test (BMDP program; Dixon and Brown 1979) showed significant differences ($P = 0$) in the number of particles ingested among the three regions. The birds in the Gulf of Alaska averaged 2.4 ± 5.9 particles per bird ($n = 634$), about two-thirds that of birds in the Aleutian Islands ($X = 3.8 \pm 11.3$ particles per bird; $n = 391$). Birds in the Bering and Chukchi Seas averaged 0.6 ± 2.2 particles per bird ($n = 413$), about one-seventh that of birds in the Aleutians and about one-fifth that of birds in the gulf. This geographic variation may be explained in terms of nonuniform geographic input of plastic and subsequent dispersal by currents.

The synthesis of plastic requires large amounts of petrochemicals; southern California and Japan are the two major petrochemical and plastics manufacturing centers in the North Pacific (Guillet 1974; Wong et al. 1976). Any plastic entering the ocean in southern California probably moves southward (i.e., away from Alaska) in the California Current system. Any plastic entering the ocean in eastern Japan probably moves eastward in the North Pacific Drift Current (see Tabata 1975 and Favorite et al. 1976; also see Wong et al. 1976, for information on "downstream" contamination of the North Pacific Drift Current east of Japan by tar balls), which splits to form the California Current and the Alaska Current. Of the plastic transported into the northern Gulf of Alaska by the Alaska Current, some apparently moves inshore and is eaten by seabirds; most of the water moves across the Gulf far offshore, however, far from where most of the seabirds examined by Day were feeding. Some plastic must also enter inshore waters there from the small population centers and fishing activities. Recent studies by Royer (1975, 1983) indicate that there is little surface divergence in this region, suggesting that most of the plastic should be carried far offshore past this region.

The Alaska Current-Aleutian Stream system flows closely along the southern edge of the Aleutian Islands (Fig. 1), and the proximity of plastic in this nearshore current to birds breeding and feeding there probably accounts for the high level of plastic ingestion observed there. Surface flow into the Bering Sea is concentrated in Near Island Pass and Commander Pass, and appears to be relatively small (Tabata 1975; Favorite et al. 1976), explaining the lower amount of plastic ingested by birds in the Bering and Chukchi Seas.

The availability of large quantities of plastic in regions of plastic production, which are more polluted than Alaska, may allow a much higher degree of ingestion than in areas remote from plastic production. A comparison of plastic ingestion between seabirds in California (Baltz and Morejohn 1976) and Alaska (Day 1980) illustrates this point (Table 10). Of seven species that were examined for plastic in both regions, all seven from California were found to ingest plastic, whereas only four from Alaska did. Of the four species that contained plastic in both regions, California birds averaged about four times as many particles per bird as did Alaska birds. Thus, we predict that seabirds foraging near areas of extensive plastic production or manufacturing will have a higher incidence of plastic and a higher mean number of particles per bird than will seabirds foraging in areas of minor plastic production or manufacturing.

Table 10.--A comparison of plastic ingestion in seven seabird species examined from Alaska and California. Data for Alaska birds are from Day (1980) and for California birds are from Baltz and Morejohn (1976).

	Sample size (n)		Frequency of occurrence (%)		Mean No. of particles per bird	
Species	Alaska	California	Alaska	California	Alaska	California
Northern fulmar	38	3	58	100	2.8	11.3
Sooty shearwater	76	21	43	43-67	1.1	6.9
Short-tailed shearwater	200	6	84	100	5.4	21.7
Mew gull	10	4	0	25	0	0.2
Glaucous-winged gull	63	8	0	13	0	0.1
Black-legged kittiwake	188	8	5	13-25	0.1	0.5
Rhinoceros auklet	20	26	0	4	0	0.1

Temporal Variation in Plastic Ingestion

Inter- and intra-annual variations in plastic ingestion have been examined by Day (1980). The primary species providing enough data to examine long-term variations in plastic ingestion is the short-tailed shearwater; samples examined by D. L. Serventy (CSIRO Wildlife Research, Helena Valley, W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, fide D. L. Serventy) range as far back as the 1950's. The general trend shows an increase in all characteristics of plastic ingestion over time, especially in the frequency of occurrence of plastic and in the mean volume of plastic per bird (Fig. 2). Given that world plastic production is increasing by about 6% each year (Guillet 1974), and that plastic litter may also be increasing exponentially (Guillet 1974), these increases in ingestion rates probably reflect the continually increasing availability of plastic in the oceans.

Laysan albatrosses in the Hawaiian Islands have also shown an increase in frequency of occurrence of plastic over time. In 1966, 76% of 100 chicks found dead contained plastic (Kenyon and Kridler 1969), whereas 90% of 50 chicks examined there in 1982-83 did (S. I. Fefer, U.S. Fish and

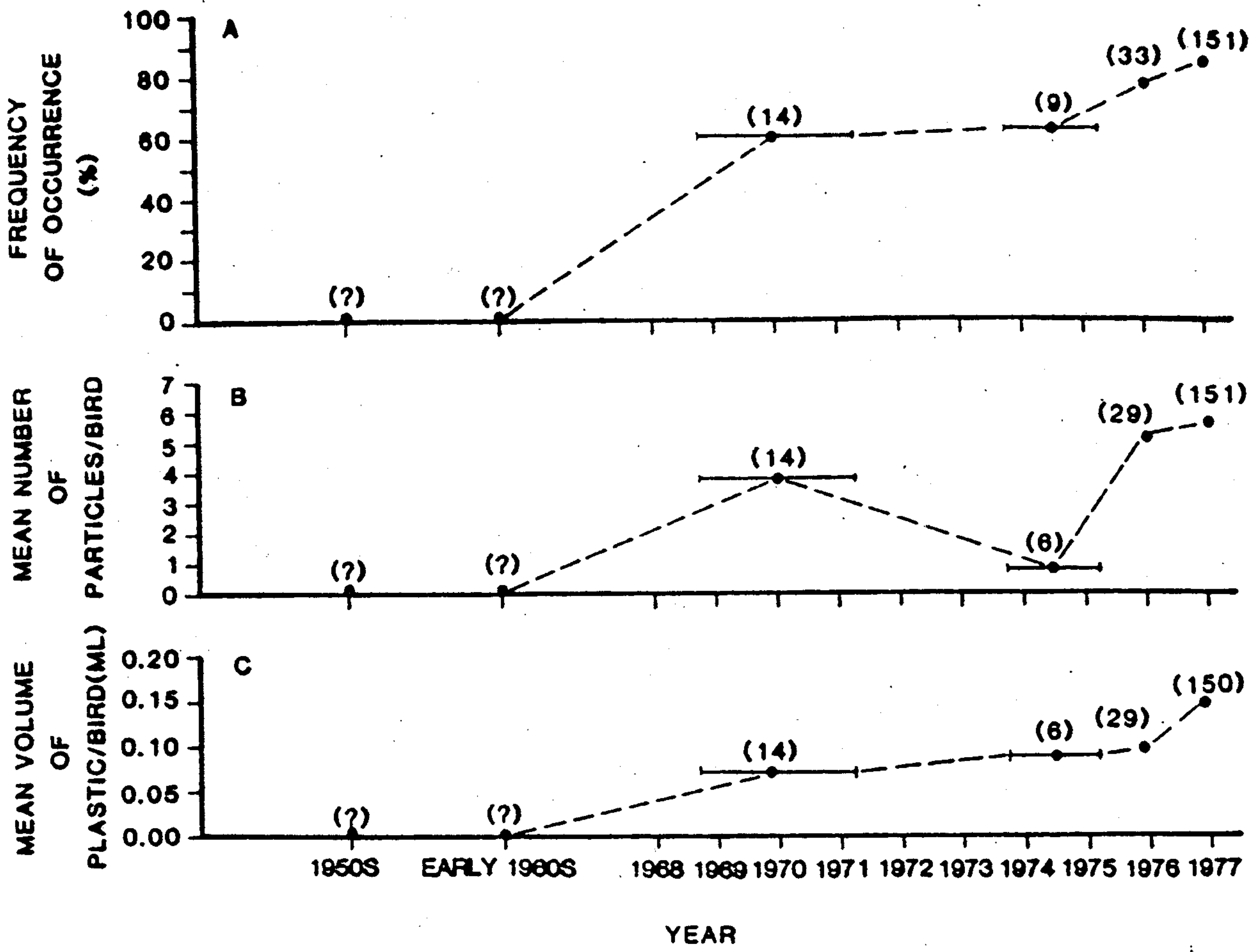

Figure 2.--Changes in plastic ingestion in the short-tailed shearwater, 1950's to 1977 (adapted from Day 1980). Sample sizes are in parentheses, and horizontal bars represent combined data for the periods 1969-71 and 1974-75. Data from the 1950's and early 1960's are from D. L. Serventy (CSIRO Wildlife Research, Helena Valley, W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, fide D. L. Serventy); they examined hundreds of short-tailed shearwaters during the course of their studies. Data from the period 1969-77 are from Alaska (Day 1980). (A) Frequency of occurrence of plastic; (B) mean number of plastic particles per bird; (C) mean volume (ml) of plastic per bird.

Wildlife Service, Hawaiian and Pacific Islands National Wildlife Refuge pers. commun.); this increase in frequency of occurrence is significant ($\chi^2 = 4.2$; $P < 0.05$).

No plastic was found in any of the parakeet auklets collected at St. Lawrence Island in the mid-1960's (J. Bedard, Universite Laval, Quebec, Canada pers. commun.), yet approximately 50% of the parakeet auklets from the Bering and Chukchi Seas contained plastic in the period 1974-77 (Table 9). Thus, it appears that ingestion of plastic by marine birds first occurred in the early 1960's in the Pacific (Kenyon and Kridler 1969) and that plastic ingestion is increasing annually; plastic ingestion also appears to have begun in the Atlantic in the early 1960's (Rothstein 1973).

Marine birds in Alaska also show intra-annual variation in plastic ingestion (Day 1980). Figure 3 shows the mean number of plastic particles per bird and the frequency of occurrence of plastic in short-tailed shearwaters collected in Alaska and Australia and in tufted puffins collected in Alaska.

In May, the mean number of particles per short-tailed shearwater was relatively small, although about 80% of the birds contained plastic (Figs. 3A, 3B). The birds began ingesting plastic in large numbers in June ($\bar{X}$ = 6.5 particles per bird). By July, the mean number of particles per bird decreased slightly, so the rate of ingestion was not so high as the rate of loss through wear. The percentage of birds with plastic had risen slightly, to 84%, indicating that ingestion was still occurring. A second period of heavy plastic ingestion occurred in August, when the mean number of particles per bird again increased; 98% of the birds contained plastic at this time. The mean number of particles ingested again declined in September, although virtually 100% of the birds contained at least some plastic. During winter, the rate of ingestion was low, as indicated by the data from Bass Strait: only 47% of the birds contained plastic, and approximately 72% of these had two or fewer particles.

Essentially the same pattern is seen in tufted puffins (Figs. 3C, 3D): Low frequencies of occurrence and low mean numbers of particles per bird in May, high rates of plastic ingestion in midsummer, and decreased ingestion rates and subsequent loss through wear late in the summer. A similar pattern was also seen in parakeet auklets and horned puffins from Alaska (Day 1980).

The frequency distributions for the wear classes (a relative grade of how worn individual particles are) of individual particles support the evidence that most plastic in boreal birds is ingested during the summer (Fig. 4). In May, only the more-worn wear classes were represented, indicating little ingestion during the winter and following the pattern predicted from the decreased ingestion rates seen in Australian birds. During June, the mean wear class decreased from 4.6 (worn-very worn) to 3.6 (relatively worn-worn), indicating that many less-worn particles were being ingested; 50% of the particles were in wear classes 1-3, the less-worn categories. The lack of wear-class 1 (fresh) particles is attributable to the likelihood that not all particles are in wear class 1 when ingested.

The frequency distributions for July and August were similar, with those particles in the stomach wearing down. The bulk of the particles was concentrated in wear classes 4 and 5, the more-worn categories. Although "fresher" particles (wear classes 1-3) were being ingested, the mean wear class increased (i.e., particles became more worn) because the newly added fresh particles constituted a proportionally smaller percentage of the number of particles than they had in May and June. The mean wear class again increased in September, and particles in the fresher wear classes only constituted 10% of the sample at this point, indicating that the rate of ingestion had decreased.

In summary, during the northern winter, the birds apparently eat little plastic. Consequently, that plastic remaining in the stomach wears down (mean wear class approaches 5) and some is lost (the mean number of

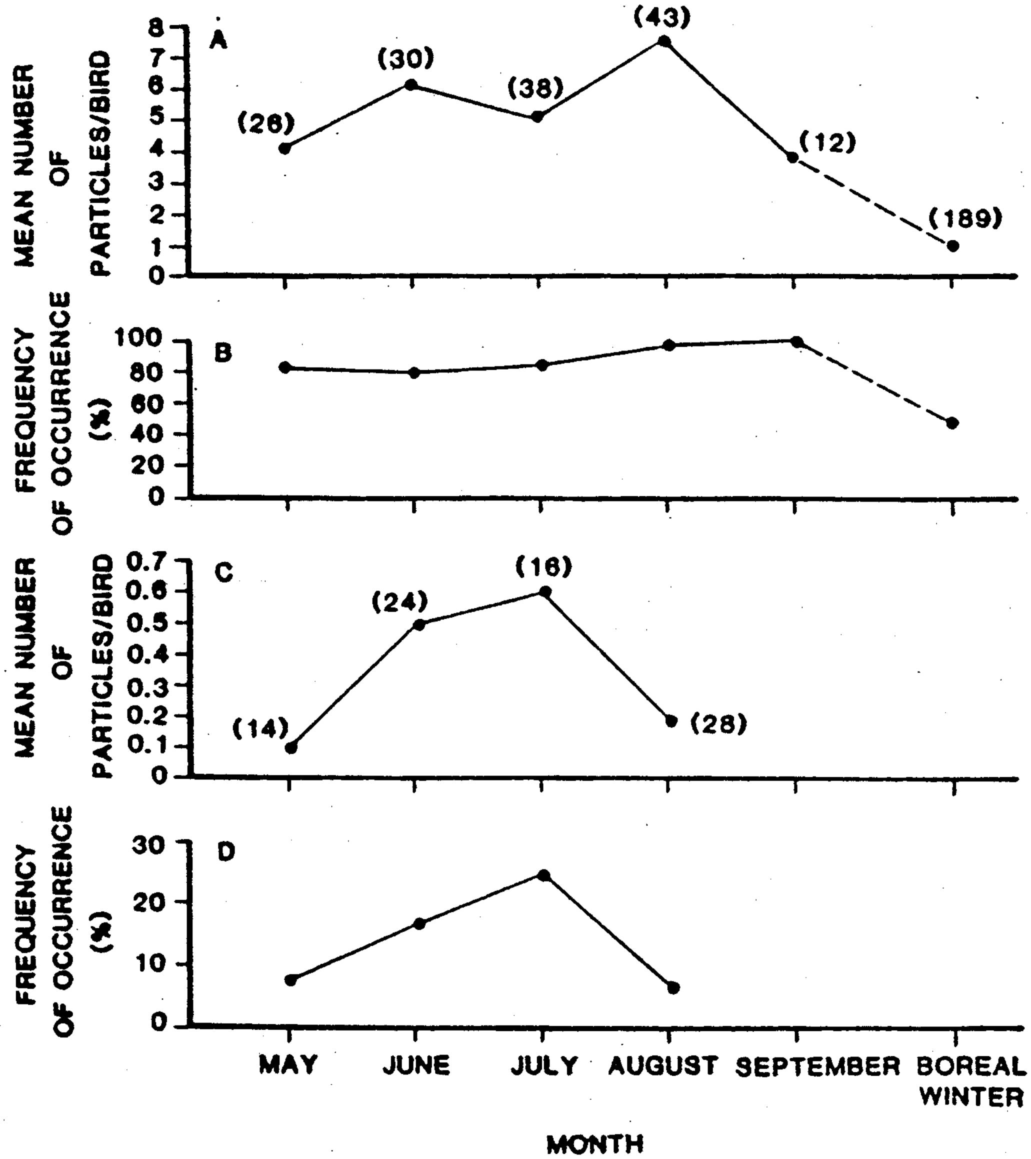

Figure 3.--Temporal variation in plastic ingestion in short-tailed shearwaters (A, B) and in tufted puffins (C, D) in Alaska (adapted from Day 1980 and Day unpubl. data). (A) Mean number of plastic particles per bird in short-tailed shearwaters of unknown age collected near Kodiak Island in 1977 and in Bass Strait, Australia, during the boreal winters of 1978 and 1979 (I. J. Skira, National Parks and Wildlife Service, Sandy Bay, Tasmania pers. commun.); sample sizes are indicated in parentheses. (B) Frequency of occurrence of plastic in short-tailed shearwaters, as above. (C) Mean number of plastic particles per bird in adult tufted puffins collected at Buldir Island in 1975; sample sizes are indicated in parentheses. (D) Frequency of occurrence of plastic in tufted puffins, as above.

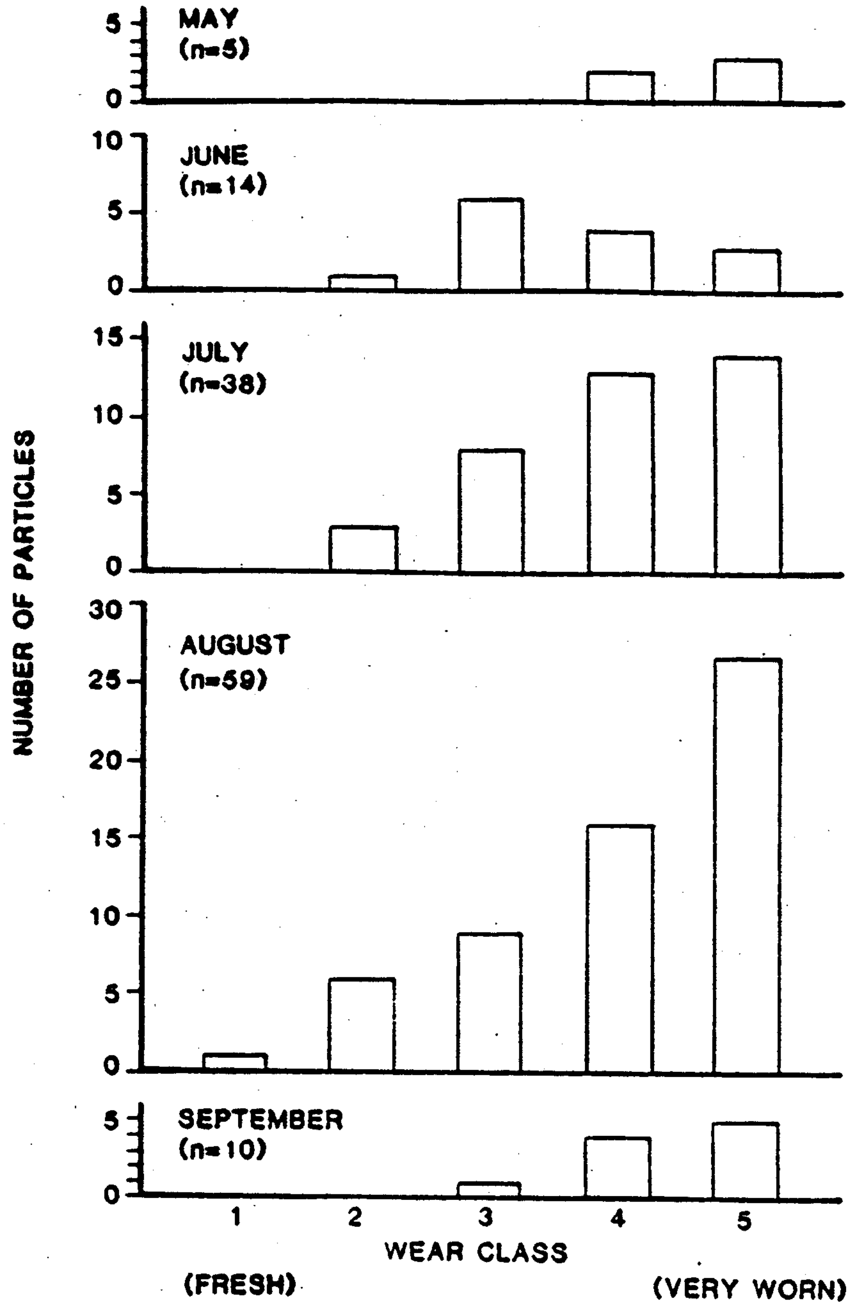

Figure 4.--Frequency distributions of the wear class of individual plastic particles found in short-tailed shearwaters collected in Alaska during the summer of 1977 (from Day 1980). All birds were collected near Kodiak Island, as in Figure 3. Wear on each piece was determined by classifying the degree of angularity of the piece's edge and by examining the general surface of each piece. The degree of wear was quantified by a five-point visual index (fresh, relatively fresh, relatively worn, worn, and very worn), as described in Day (1980).

particles per bird decreases). This condition exists until May. In late spring and early summer, the birds again begin eating plastic, causing a sharp rise in the mean number of particles per bird and a sharp decrease in the mean wear class of the plastic, as seen in the June birds. In contrast to the June data, midsummer (July and August) means show relatively little change, indicating that consumption of new particles is roughly balanced by loss of particles through wear. The ingestion of plastic decreases near the end of the summer, and smaller particles continue to be lost through wear; the mean number of particles per bird decreases, and the mean wear class approaches 5 (very worn) again. Wear then continues into the winter months, completing the cycle. Although migratory seabird species from higher latitudes appear to ingest plastic only during some months, it is believed that nonmigratory tropical species are able to ingest plastic all year (S. I. Fefer pers. commun.).

Since the particles do not pass into the intestine, the mean residence time of plastic in the birds' stomachs may be estimated. Although Day (1980) estimated residence times of 2-3 months for "soft" polyethylene and 10-15 months for "hard" polyethylene, the data showing rapid loss rates in short-tailed shearwaters and tufted puffins presented here and data for phalaropes from Connors and Smith (1982) suggest that the mean residence time of individual particles is shorter and is on the order of 6 months. Obviously, there could be great variation in these rates, depending on the number, size, and type of particles and other hard objects (e.g., pumice) in a particular bird's stomach.

The available data permit examination of the impact of the birds' ingestion of the at-sea density of plastic. At the peak of summer ingestion, short-tailed shearwaters average about 7.4 particles per bird (Fig. 3). With an estimated population of 18×10^6 birds (I. J. Skira pers. commun.), this yields an estimated "standing stock" of 133×10^6 particles in the stomachs of this species. The average residence time of the particles is estimated to be 6 months. Therefore, the average removal of plastic by this species is approximately 0.7×10^6 particles per day in the middle of the summer. The peak of plastic ingestion by the short-tailed shearwater was in June, with a mean increase of 2.1 particles per bird; thus, a peak of 1.3×10^6 particles per day were removed from the ocean during June by this species.

Shaw (1977) estimated that plastic density in Alaska waters is about one piece per 9,000 m^2 of ocean surface (= 111.1 pieces per km^2); using a rough estimate of 3.0×10^6 km^2 of ocean surface in the waters around Alaska, we estimate that there are approximately 333×10^6 pieces of ingestible plastic in the waters around Alaska. The rate of "recruitment" into this "plastic population" is probably low, since estimates of water circulation times in the subarctic North Pacific range between 2 and 5 years (T. Royer, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). When one considers that the short-tailed shearwater alone removes about 80×10^6 particles from the waters around Alaska during June and August (primarily in shelf and shelf-break waters), and that other species are ingesting plastic at the same time, it appears that birds are decreasing the at-sea density of plastic in Alaska waters. Although our estimates of rates of ingestion may be high and Shaw's estimates of plastic density may be low, it is apparent that the birds are decreasing the density of plastic enough to cause the synchronous late-summer decline in ingestion seen in all species (Fig. 3).

Effects of Plastic Ingestion on the Physical Condition and Reproduction of Marine Birds

Perhaps the most important question to be asked about plastic ingestion is whether or not the presence of plastic in the gut has a detrimental effect on the physical condition or reproductive performance of the birds. These effects could take several forms, including direct ones such as starvation, intestinal blockage, ulceration, and internal injury, or indirect ones, such as decreased physical "quality" or reproductive performance.

Starvation could be caused by the physical presence of plastic in the stomach. In birds, hunger and satiety are regulated by receptors in the hypothalamus, where various stimuli reaching the central nervous system influence food intake (Sturkie 1965). Appetite (hunger) can be stimulated by the contraction of an empty stomach, cold temperatures, or the sight of food, and can be inhibited (satiety) by dehydration, distension of the stomach or intestines, warm temperatures, or exercise (Sturkie 1965). A large amount of plastic in the stomach of a bird could decrease feeding activity by maintaining stomach distension and preventing stomach contraction, thus signaling "satiety" to the hypothalamus. Although plastic has been associated with starvation in some birds (Bond 1971; Bourne and Imber 1982), Bourne and Imber correctly pointed out that one must be careful with this interpretation, for it is often difficult to determine if the plastic ingested caused the starvation or if the plastic was ingested because the bird was starving.

Intestinal blockage--preventing the passage of food into the intestine--can only occur if a bird eats a large volume of plastic or a particularly bulky piece of plastic. Intestinal blockage by elastic thread cuttings (Parslow and Jeffries 1972) and by nylon threads (Bourne 1976), which tend to roll into a ball in the stomach (Parslow and Jeffries 1972; R. H. Day pers. observ.), has also been documented. Intestinal blockage by large, bulky items has been documented in Laysan albatross chicks (Kenyon and Kridler 1969; Pettit et al. 1981; S. I. Fefer pers. commun.).

Ulceration and internal injury could be caused by the presence of jagged edges on plastic fragments or by a long period of contact between the plastic and the mucosa of the stomach wall. Van Franeker and Camphuijsen (1984) found a nail embedded in a thick layer of fatlike material in the distal part of the gut of a northern fulmar. Local ulcerations of stomach mucosa as a result of plastic ingestion have been recorded in northern fulmars (Bourne 1976) and in Laysan albatross chicks (Pettit et al. 1981; S. I. Fefer pers. commun.).

Indirect effects of plastic ingestion may take the form of decreased physical "quality" of the bird or decreased reproductive performance. To test for the effects of plastic ingestion on the physical quality of the birds, Day (1980) calculated linear regressions for the number, weight, and volume of plastic particles versus the body weight and body fat class of short-tailed shearwaters and parakeet auklets from Alaska. In all cases, weak ($r^2 \leq 0.17$) negative slopes were found for the lines, and the lines were not significantly different from zero ($P > 0.05$), indicating a slightly negative and weak relationship between increasing amounts of plastic and weights of the birds. No relationship was found when the above variables were plotted against body fat class. Thus, plastic ingestion had limited effects on the physical quality of these birds, at least in terms of body weight and body fat condition. A negative relationship between the amount of plastic and body fat condition has been found in red phalaropes in California, however (Conners and Smith 1982).

The ingestion of plastic may have detrimentally affected the reproduction of parakeet auklets in Alaska in 1976 (Day 1980). Nonbreeding adults average twice as many particles ($\bar{X} = 34.3 \pm 23.9$ particles per bird; $n = 12$) as did breeding adults ($\bar{X} = 17.4 \pm 16.3$ particles per bird; $n = 25$); these differences were significant ($T = 216.5$; $P < 0.01$; Mann-Whitney one-tailed test; Conover 1971). The nonbreeder category included failed breeders and birds that had bred in previous years. Some of the parakeet auklets had up to 81 pieces of plastic in the stomach, which appeared to distend the stomach fully. In several cases, many of the particles had become embedded in "sockets" that had formed in the mucosa of the stomach; under these conditions, the presence of plastic appears to have been detrimental to the function of the stomach. Day (1980) suggested that the decrease in reproductive performance also could have been related to decreased feeding during the prebreeding season.

Another interpretation of this observation is possible. Since, as we have shown, there is age-related variation in the amount of plastic ingested by subadult versus adult parakeet auklets (Table 8), there is a possibility that there is also age-related variation in plastic ingestion within the "adult" category. If this is true, young adults would ingest more plastic than would older adults. Young adult seabirds tend, in general, to increase in reproductive success with increasing age and experience, and many fail at reproduction in their first or second years of breeding (Richdale 1957; Asbirk 1979; Thomas 1983). As a result, the observed poor reproductive success of parakeet auklets containing large amounts of plastic may have actually been the result of normally poor reproductive success of first or second time breeders.

A decrease in reproductive performance could also result from hydrocarbon pollutants associated with plastic. Hydrocarbons such as DDE and polychlorinated biphenyls (PCB's) are suspected of lowering the levels of one or more steroid hormones, resulting in delayed ovulation (Peakall 1970); any delay in normal reproductive cycles in arctic seabirds may contribute to reproductive failures. Although no data are available for raw polyethylene pellets, polystyrene spherules have been found to have PCB's concentrated from seawater onto their surfaces (Carpenter et al. 1972). An increase in the number of particles ingested would thus bring more hydrocarbons into the birds' bodies, preventing successful reproduction.

An explanation alternative to our interpretation can be proposed from the above data. Birds in poor condition may eat more plastic than do healthy birds because they are in poor condition; since these birds are already in poor condition, they probably will not reproduce anyway, yielding the same results. This possibility notwithstanding, the likelihood of decreased reproductive performance as a result of plastic ingestion warrants further investigation.

DISCUSSION AND CONCLUSIONS

Sources of Plastic

Two major types of plastic are ingested by marine birds: plastic fragments and raw plastic pellets. Other types of plastic such as polystyrene spherules, foamed polystyrene (i.e., styrofoam), toys, and other objects, are eaten by seabirds only rarely (Day 1980). Only Laysan albatrosses eat much of these latter types of plastic (S. I. Fefer pers. commun.).

The primary sources of plastic fragments appear to be at-sea solid-waste disposal and (particularly) by discarding plastic objects from fishing boats and marine shipping (Scott 1972, 1975; Cundell 1973; Venrick et al. 1973; Colton 1974; Shaw 1977; Feder et al. 1978; Merrell 1980; Morris 1980a). In the early 1970's, for example, approximately 4.5×10^4 metric tons of plastics were discarded at sea each year (National Academy of Sciences 1975 cited in Merrell 1980); Guillet (1974) contends that plastic packaging litter is presently increasing at an exponential rate. Some of the nearshore plastic evidently comes from nearby population centers (e.g., Cundell 1973), although currents and winds play a major role in distributing most of this debris far from its origin (e.g., Venrick et al. 1973; Scott 1975; Merrell 1980). This larger debris is subsequently broken into smaller fragments, which are then ingested by seabirds. The areas of origin of this widely dispersed plastic are often difficult to determine. Studies in the Pacific Ocean, however, have shown that 108 of 109 identifiable plastic items eaten by Laysan albatrosses from the Hawaiian Islands originated in Japan (Pettit et al. 1981) and that most of the litter found on beaches in the Aleutian Islands originated from Japanese and American fishing boats (Merrell 1980). At the latter site, countries represented by identifiable plastic litter were Japan, the United States, the U.S.S.R., Republic of Korea, Canada, Bulgaria, Rumania, and the Netherlands, in order of decreasing frequency. Work in Scotland has shown that most of the plastic debris there also comes primarily from shipping (Scott 1975).

Raw polyethylene pellets are the raw form of polyethylene as it is synthesized from petrochemicals; these pellets are then shipped around the world to manufacturing sites, where they are melted down and fabricated into bags, squeeze bottles, toys, and many other everyday items. Because these pellets are shipped worldwide, the origins of pellets found at sea are difficult to determine. Although the country of origin of these pellets cannot be determined, there are many ways in which they enter the sea. Many pellets probably enter the sea in effluents from plastic-synthesis plants, as has been reported for polystyrene in the North Atlantic (Kartar et al. 1973, 1976; Hays and Cormons 1974; Morris and Hamilton 1974). In Goa, India, plastic factories simply dump their waste plastic into the nearby river, which then carries it to the sea (Nigam 1982). Pellets are also used as packing around larger objects in ships' holds and sometimes are moved in bulk, as is grain; errors in loading and unloading ships at ports allow escapement into the sea. Pellets are sometimes used on the decks of ships to reduce friction for moving large objects, then are washed from the decks and into the sea (Anonymous 1981). After entering the sea, pellets are dispersed through the world's oceans by currents and winds.

There are several mitigating actions that could reduce entry of plastics into the oceans. Filtering effluents from synthesizing-manufacturing plants is relatively easy and will save the companies money. Reducing effluent loss of polystyrene spherules from manufacturing sites in the United Kingdom caused a rapid reduction in ingestion of those spherules by organisms in nearby waters within 3 years (Kartar et al. 1976). Improving loading and unloading procedures at docks would also decrease entry into the oceans. Reductions in the at-sea discarding of plastic litter could be effected by making litter control a requirement for fishing permits (as suggested by Merrell 1980) or by making shipboard incinerators a requirement for licensing a ship.

Another mitigating action is to alter the degradation rates of the plastics themselves. Guillet (1974) and Gregory (1978, 1983) have shown that weathering of polyethylene and styrofoam occurs naturally and eventually leads to disintegration and dispersal as "dust." Gregory (1983) stated that it would require 3-50 years for complete disintegration to occur on the beach, and apparently much longer at sea. One way to accelerate degradation is to make the plastics highly degradable under normal conditions. The plastics industry has encountered many practical problems in trying to produce degradable plastics, however (Taylor 1979; contra Guillet 1974), leaving regulation of loss into the sea as a more feasible and realistic method of reducing the abundance of plastic in the oceans.

Rates of Ingestion in Marine Birds: A Look to the Future

We feel that it is appropriate to discuss the monitoring of species or groups of seabirds for rates of plastic ingestion. Those species or groups ingesting the most plastic (either with the highest frequencies of occurrence or the highest mean number of particles per bird) should be monitored closely in the future. As we have shown, procellariiform birds are the seabirds most vulnerable to plastic pollution (Tables 1-3). A high percentage of the species examined contain plastic, the two highest average amounts of ingestion occurred in this group, and the earliest records of plastic ingestion by marine birds were from this group (Kenyon and Kridler 1969; Rothstein 1973). Procellariiform birds tend to scavenge at sea and to ingest randomly any plastic that they encounter (Table 7; Ashmole 1971; Day 1980; Day pers. observ.). They also tend to eat large or oddly-shaped plastic objects (see comments in Table 2) that may cause intestinal blockage or internal injury (e.g., Bourne 1976; Pettit et al. 1981). These birds also pass ingested plastic on to their chicks through regurgitation-feeding (e.g., Kenyon and Kridler 1969; Rothstein 1973), perhaps increasing prefledgling mortality. Procellariiform birds also feed at or near the sea's surface and eat a high frequency of crustaceans and cephalopods (Ashmole 1971), two prey groups that are correlated with high rates of plastic ingestion (Tables 4, 5). On the other hand, procellariiform birds are able to eliminate some plastic by egesting casts containing indigestible items, such as squid beaks.

Another species of major concern is the parakeet auklet (Table 2). This species averaged the highest number of plastic particles of 37 species of seabirds in Alaska, 13.7 particles per bird, and showed evidence of decreased reproductive performance there as a result (Day 1980). This species preys primarily on crustaceans, a prey group linked to high rates of ingestion of plastic (Table 5). Some of the stomachs examined by Day were fully distended because so much plastic was present. Phalaropes also should be monitored closely for ingestion, because the few data available (Table 2) indicate a capacity for high rates of plastic contamination. At present, the other species of seabirds appear to have low rates of plastic ingestion, indicating that less-intensive monitoring is needed.

Monitoring should be done at selected sites in the Northern and Southern Hemispheres and in all oceans. Birds found dead on beaches and birds collected for museums should be examined closely for frequencies of ingestion and for the amount of plastic ingested; birds found dead should also be checked for the cause of death and chlorinated hydrocarbon levels should be determined. Any sampling gaps can then be filled with selective collecting of species of interest. We suggest a 2- or 3-year cycle for monitoring.

Feeding Habits and Plastic Ingestion

A few species of seabirds evidently ingest at random any plastic or objects that they encounter. Before the production of plastics, most objects encountered by birds at the sea's surface were digestible (except for floating pumice); selection may have favored those species that ingested any such objects (Rothstein 1973). Many species, however, select for specific kinds, colors, shapes, color-shape combinations, or sizes of plastic (Day 1980). Such selection suggests that these species are mistaking plastic objects (a recent addition to the surface of the ocean) for prey items. Prey items that the light-brown pellets most resemble to the authors are planktonic crustaceans and pelagic fish eggs. Other colors of pellets may resemble the eyes of fishes or squids, the bodies of larval fishes, or other, unknown food items.

It is likely that not a single factor, but a suite of (sometimes) interacting factors, affects the amount of plastic ingested by seabirds. These factors include the feeding method and prey type of the species, the tendency for generalism or specialization in feeding habits, age of the birds, time of year, at-sea density of plastic, and geographic location of the birds.

The Problem of Effects of Plastic Ingestion

It is unfortunate that we still do not know the true extent of the effects of plastic ingestion. We suspect that, for most species, the rates of ingestion and the amounts of plastic ingested are low enough that there is little detrimental effect on the birds involved. There are several species, mentioned earlier, that have been shown to exhibit sufficiently high rates of ingestion to warrant concern. Decreased feeding rates before breeding may result in poorer physical condition of the bird, leading to an inability to secure or maintain a breeding territory, to lay high-quality eggs, or to successfully incubate those eggs. Data from parakeet auklets

(Day 1980) suggest that any or all of these conditions may apply to that species, and data from short-tailed shearwaters (Day 1980) and red phalaropes (Connors and Smith 1982) suggest a link between high amounts of plastic ingested and decreased physical "quality." The possibility of hydrocarbon contamination through plastic ingestion (Carpenter et al. 1972) also has serious implications. Consequently, we believe that carefully controlled experiments on the effects of plastic ingestion need to be performed to determine whether or not a serious problem really exists. These experiments could conceivably be performed in conjunction with zoos or schools of veterinary science.

ACKNOWLEDGMENTS

We thank the following individuals and organizations for aid rendered in connection with this study: J. Bedard, M. S. W. Bradstreet, E. W. Chu, A. W. DeGange, D. V. Derksen, T. J. Dixon, S. I. Fefer, C. S. Harrison, G. L. Hunt, Jr., M. J. Imber, R. Mykytowycz, M. Naughton, H. Ogi, G. A. Sanger, G. Searing, D. L. Serventy, I. J. Skira, and R. S. Wood all generously provided us with many of the samples and data upon which this study was based. Special thanks go to G. L. Hunt, Jr., M. J. Imber, and the personnel of the U.S. Fish and Wildlife Service, Anchorage, Alaska. Part of the funding to do this research was provided by the U.S. NOAA/BLM Outer Continental Shelf Environmental Assessment Program and by the Vice-Chancellor for Research and Advanced Study, University of Alaska, Fairbanks, Alaska. The 1984 data were gathered aboard the TV _Oshoro Maru_ of Hokkaido University, Hakodate, Japan; special thanks go to Captain Y. Masuda and T. Minoda, M. Kajihara, and H. Nakano. D. G. Shaw analyzed the chemical composition of the plastic samples from Alaska. E. C. Murphy and D. P. Pengilly provided statistical advice and performed some analyses. This manuscript was improved by comments from G. J. Divoky, D. D. Gibson, S. I. Fefer, B. Kessel, B. E. Lawhead, S. F. MacLean, Jr., C. P. McRoy, P. G. Mickelson, E. C. Murphy, and P. G. Ryan. Funds to attend this meeting were provided by the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, and by the University of Hawaii Sea Grant Program. This is Contribution No. 577 of the Institute of Marine Science, University of Alaska, Fairbanks, AK 99701.

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IMPACT OF OCEAN DEBRIS ON MARINE TURTLES: ENTANGLEMENT AND INGESTION

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ABSTRACT

Marine turtles are affected to an unknown but potentially significant degree by entanglement in, and ingestion of, synthetic oceanic debris. Nearly all known records of olive ridley turtle, Lepidochelys olivacea, in the Hawaiian Islands have resulted from entanglement in drifting scraps of fishing gear. In the North Pacific (lat. 35°-45°N), incidents of leatherback turtle, Dermochelys coriacea, fatally entangled in pieces of monofilament mesh have been recorded. However, as with many such cases involving marine turtles, it is unclear if entanglement occurred in discarded fragments or in intact gear being actively fished.

Marine turtles have been found to eat a wide array of synthetic drift items, including plastic bags, styrofoam beads, and monofilament fishing line. Toxic chemicals released by these materials, as well as physical obstruction to the digestive tract, are two possible adverse impacts.

INTRODUCTION

International efforts to conserve and manage sea turtles effectively have been periodically hampered by the discovery of new or previously unidentified impacts on surviving populations. Sea turtles are already known to be directly threatened by an array of human activities on nesting beaches and in marine foraging habitats. Major impacts include intensive exploitation for meat, eggs, shell, and skin (all of which are often taken for commercial purposes), the incidental capture and drowning of turtles in shrimp trawls, and alteration of habitat by coastal development. Other problems that have received far less attention in the literature include petroleum and toxic chemical pollution, incidental catch by a variety of fisheries (e.g., pound nets, gill nets, drift nets, purse seines, longlines, lobster and other types of traps), ingestion of plastics and tar, disease, cold waves, and predation by large sharks. Considered separately, each of these lesser known impacts may not necessarily cause high rates of mortality or morbidity. However, their combined effect over an extended

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

period could very well be a significant retardant to the recovery of certain populations. It is, therefore, imperative that each adverse element be adequately examined and understood.

All sea turtles have been legally protected in the United States since 1978 under provisions of the Endangered Species Act. A number of other countries have also implemented protective measures in recent years and engaged in cooperative efforts to conserve and study these turtles (Bjorndal 1982; Groombridge 1982; Bacon et al. 1984).

A basic problem in determining the scope and magnitude of impacts on sea turtles is that all species lead an oceanic existence during portions of their life history. Broad gaps exist in the knowledge of sea turtles away from land because they are seldom seen, let alone studied. In contrast, reasonably good ecological data exist for the breeding phase when adult females, eggs, and hatchlings are accessible on land. The leatherback, _Dermochelys coriacea_, and olive ridley, _Lepidochelys olivacea_, seem to be the most pelagic species, living well offshore from the time they leave the beach as hatchlings until they return to breed as adults. Others like the green turtle, _Chelonia mydas_, loggerhead, _Caretta caretta_, and hawksbill, _Eretmochelys imbricata_, inhabit coastal waters as adults, but spend varying segments of their immature life in the open ocean. Even then the adults regularly undertake breeding migrations which place them for a time over deep water. The limited information available on the Australian flatback, _Chelonia depressa_, and the severely depleted Kemp's ridley, _Lepidochelys kempi_, suggests that these species also pass through pelagic phases of development.

Man-made debris floating at the surface in the same oceanic habitat occupied by sea turtles presents a potential for substantial interaction. The amount of refuse now entering the world's oceans, especially plastics and tar, appears to have reached huge proportions (Carpenter and Smith 1972; Venrick et al. 1973; Wong et al. 1974, 1976; Morris 1980a, 1980b; Van Dolah et al. 1980; Eldridge 1982). For example, Horsman (1982) estimates that 639,000 plastic containers (including bags) are dumped into the sea daily from merchant ships alone. Floating material of a natural and synthetic nature is known to collect in drift lines that result from converging offshore currents or strong winds sweeping the sea surface. In the Caribbean, where rafts of sargassum are prominent, such areas are believed to be preferred habitat for some, and possibly most, small sea turtles of the region (Fletemeyer 1978; Carr and Meylan 1980; Carr 1983). A similar situation probably occurs in the Pacific and elsewhere, although sargassum rafts would not be a common feature since in many areas they do not exist. Plastic particles, tar, and other floating debris that aggregate in drift lines are likely to be consumed by turtles that normally feed on small surface-dwelling invertebrates and other plankton. Another form of discarded plastic, transparent bags and sheets, has also been implicated in recent years as being harmful to sea turtles, particularly adult leatherbacks. This material is apparently mistaken for drifting jellyfish (Scyphomedusidae), a principal food item of the leatherback.

Another aspect of the debris problem--the entanglement of turtles in floating and bottom-fouled scraps of line, net, or other lost or abandoned gear--has only infrequently been noted in the literature. Unlike the ingestion of plastic bags, little publicity has appeared in the mass media on debris entanglement. Because turtles are incidentally caught in many kinds of fisheries, there is difficulty in determining whether entanglement actually involves debris per se, or represents capture in actively fished gear that somehow tore free. Nevertheless, it is apparent that sea turtles are prone to all kinds of entanglement as a result of their body configuration and behavior. Entanglement in debris may therefore be best considered as an extension of the incidental catch problem.

The phenomena of sea turtles ingesting and becoming entangled in debris have not previously been the subject of a comprehensive review. The objective of this paper is to assemble and evaluate existing information, most of which is scattered throughout the literature or contained in unpublished records. The availability of a consolidated source of data may then serve as a useful starting point to assess the scope and magnitude of the problem. It will also provide a basis for determining what future research is needed to address the problem adequately.

METHODS OF DATA COLLECTION

Documented records of turtles that had ingested or become entangled in debris were compiled through an extensive literature search, and by personal inquiries to numerous researchers worldwide. In addition, a relatively large number of unpublished cases for the Hawaiian Islands were included that had been gathered by the author since 1973.

To the extent that they exist, pertinent details from each case were abstracted and assembled in an annotated data table. This information included the species of turtle, date, location, carapace length, weight, sex, and a concise description of the event, often with quotations from the original source. For cases of ingested debris, usually only synthetic items were listed, and not the natural food items present. The literature citation or other origin of the report was also entered into the data table. Summaries of all cases were tabulated to identify geographic distribution, species involved, age composition of the turtles, and types of impacting debris.

In accomplishing this study, it was realized that many more cases undoubtedly exist than are contained herein. With the circulation of this paper, it is hoped that old and new reports of debris ingestion and entanglement will be sent to the author for use in a future revision.

RESULTS

Overall Findings

Concise case-by-case descriptions of debris ingestion and entanglement by species are presented in Tables 1 and 2. It was possible to locate 79 reports dealing with ingestion (Table 1) and 60 dealing with entanglement (Table 2). None of the cases occurred before the 1950's; 95% have taken place since 1970.

Debris ingestion involving only single turtles comprises 60% of the cases shown in Table 1, while 32% cover multiple accounts representing at

Table 1.--Worldwide records of the ingestion of oceanic debris by marine turtles.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
				***Chelonia mydas*, green turtle and *C. agassizi*, black turtle**	
I-Cm-1	Late 1950's	Golfito, Costa Rica (Pacific coast)	--	Mass mortality attributed to the ingestion of plastic banana bags thrown from a wharf.	A. Carr. pers. commun. cited in Cornelius 1975; Hirth 1971b; Wehle and Coleman 1983; Meter 1983.
I-Cm-2	1958, 1976-77	Tortuguero, Costa Rica	Adult, F	"Some rather unconventional kinds of food" were consumed in the internesting habitat, including terrestrial plant material. Four of 11 turtles (37%) had eaten plastic, and 2 (18%) had eaten cloth.	Meylan 1978.
I-Cm-3	1972-73	Ascension Is.	--	"When refuse is dumped from ships or from shore, turtles sometimes move in to feed on it." Turnip tops have been found in stomachs.	Carr et al. 1974; A. Carr pers. commun. cited in Coston-Clements and Hoss 1983.
I-Cm-4	1979	Pisco, Dep. Ica, Peru	52 to 89 cm	Nine of 39 stomachs (23%) examined contained plastic bags.	Brown and Brown 1982.
I-Cm-5	Ca. 1980	New South Wales, Australia	"Subadult"	Washed ashore freshly dead "with length of fishing line hanging out both its mouth and cloaca." Preserved in the Australian Museum (Sydney) but not dissected.	C. Limpus pers. commun.
I-Cm-6	1/4/72	Kochi Prefecture, Japan	S-43 cm	"Vinyl film" found in stomach.	I. Uchida pers. commun.
I-Cm-7	9/5/83	Wakasa Bay, Fukui Prefecture, Japan	S-74 cm, 55 kg, F	Orange, yellow, and green pieces of synthetic line found in stomach. Also a transparent plastic bag and pieces of a synthetic fishing net with fish eggs attached.	I. Uchida pers. commun.
I-Cm-8	9/69	Iles Scilly (Motu-Honu), Fr. Polynesia	--	Long piece of plastic found in one of several stomachs examined.	Hirth 1971a, 1971b.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-9	10/23/81	Fakaofo Atoll, Tokelau (lat. 9°22'S, long. 171°16'W)	C-105 cm, F	Entire digestive tract empty except for a 2 by 15 cm piece of blue plastic sheet.	Balazs 1983b.
I-Cm-10	1976	Kwajalein, Marshall Is.	---	Turtles scavenge on kitchen scraps that are thrown into the ocean each day from the U.S. military facility.	Pritchard 1977.
I-Cm-11	1974-79	Hawaiian Is.	---	Items occasionally found in the digestive tract include hard plastic fragments, pieces of plastic bags, cloth, small diameter line, and terrestrial vegetation. Also tar stains in the mouth.	Balazs 1980.
I-Cm-12	1975	Oahu, Hawaii, U.S.A.	30 cm	Turtle that had been reared in captivity from a hatchling ingested a sheet of transparent plastic ca. 20 by 20 cm that accidentally fell into its pen. Twisted tip of plastic seen protruding from cloaca and pulled out. Turtle appeared unharmed. It is unknown if turtle could have voided plastic without assistance.	G. Balazs unpubl. data.
I-Cm-13	12/13/76	Tern Island, FFS, NWHI	S-45 cm	Fresh dead stranding 19 months after release from captive rearing. Sighted regularly during this period feeding on food scraps discarded by U.S. military facility. Digestive tract contained synthetic fiber cloth 8 by 20 cm, and numerous fish bones. Cause of death undetermined.	G. Balazs unpubl. data.
I-Cm-14	5/82	Midway, NWHI	C-36 cm	Man-made fibers in stomach, as well as crab legs and Janthina. Same as Case E-Cm-8 found entangled in a scrap of blue net.	G. Balazs and M. Pillos unpubl. data.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-15	10/78	Lanai, Hawaii	C-96 cm, F	Large pieces of black and transparent plastic bags twisted throughout the intestines of a turtle speared by a fisherman. Plastic in feces near cloaca suggested that blockage had not occurred.	Balazs 1980.
I-Cm-16	2/9/76	Hutchinson Is., Florida, U.S.A.	10 cm	Found dead on the beach with tar in its mouth. Had been released 20 days earlier following captive rearing.	Witham 1978.
I-Cm-17	8/2/77	Merritt Is., Florida, U.S.A.	32 cm	Found in the surf zone "upside down and disoriented." Tar was removed from the mouth, and the turtle recovered.	L. M. Ehrhart pers. commun. cited in Witham 1978.
I-Cm-18	1978-79	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small"	Weathered petroleum (tar) sealed the mouths and nostrils. Impacted turtles can be cleaned using vegetable oil or a soapless hand cleaner followed by thorough rinsing. This procedure "rehabilitated some tar-impacted turtles, but all oiled turtles died." "Widespread dispersal of petroleum residues suggests that indeterminate numbers of sea turtles may be dying at sea." "27 small sea turtles of three species were handled," but the number of green turtles was not stated. See also Case I-Cc-8 and I-Ei-43.	Witham 1983.
I-Cm-19	9/5/80	Port Canaveral, Florida, U.S.A., (lat. 28°24'30"N, long. 80°35'00"W)	12 cm	Found alive with "tar ball" in mouth. Treated and released. Turtle had previously been reared in captivity by the Florida Department of Natural Resources.	Mann and Lee 1981.
I-Cm-20	2/14-19 1981	Hutchinson Is., Florida, U.S.A.	9 to 14 cm	Seven turtles found stranded alive with tar in mouth and on body.	Anonymous 1981a.
I-Cm-21	2/18/81	Indian Harbor Beach, Florida, U.S.A.	14 cm	Found alive with dense tar packed in the throat. Treated and released 3/24/81.	Anonymous 1981b.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-22	4/20/82	Long Key, Florida, U.S.A. (lat. 24°45'N, long. 80°45'W)	18 cm	Found alive covered with tar which had also been ingested.	Roche and Witham 1982.
I-Cm-23	6/29/82	Homestead Bayfront Park, Florida, U.S.A. (lat. 25°30'N, long. 80°25'W)	22 cm, 16 cm	Live strandings with tar in mouth and covering body.	Kasqowitz 1982.
I-Cm-24	9/14/84	Mustang Island, Texas, U.S.A. (lat. 27°49.8'N, long. 97°03.3'W)	S-5.6 cm	Dead stranding with tar in roof of mouth and "minute pieces of plastic-colored foil and spherule of plastic used when polyethylene is cast." Pieces of three flippers missing.	A. F. Amos pers. commun.
I-Cm-25	10/9/84	Kaena Point, Oahu, Hawaii	S-35 cm	Died 1 day after being found floating offshore and unable to dive. Turtle not emaciated. Intestine contained a distinct blockage consisting of frayed plastic line and hard dried fecal matter.	G. Balazs unpubl. data.
			Caretta caretta, loggerhead turtle		
I-Cc-1	10/67	Madeira (lat. 32°45'N, long. 17°W)	--	Pieces of plastic in the stomach. "Like picknickers may litter the countryside with refuse, ships are beginning to litter the surface of the sea. While cruising in an area north of the Azores, where sometimes a day or two went past without ships being sighted, their presence at sea was demonstrated by boxes, jars, etc., made of plastic floating on the surface of the sea. Apparently turtles mistake these objects for food and swallow them. One wonders whether in the end the intestine of the turtle will not become blocked by such undigestable matter.	Brongersma 1968, 1969.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-2	1968-73	Cape Agulhas, South Africa	6.6 cm	Strandings of posthatchlings revealed that 2 of 32 stomachs (6%) with contents contained small plastic beads (1-2 mm cylinders and two 1-mm sphere). Pieces of fine plastic sheet 2 by 3 cm were found in two other turtles. The nature of identifiable contents "suggests that loggerhead hatchlings will eat anything that is floating and small enough to swallow."	Hughes 1970, 1974a.
I-Cc-3	<1974	South Africa	C-60 to 70 cm	Stomach contents from four of nine turtles (44%) contained synthetic debris including plastic strip, plastic bags, and pieces of glass. Bark and sugarcane also present.	Hughes 1974b.
I-Cc-4	8/2/75	Cabrera, Balearic Is., Mediterranean	40 cm, 10 kg	Intestines contained pieces of plastic, rope, tar, and onion.	Salvador 1978.
I-Cc-5	>1974	Cumberland Is., Georgia, U.S.A.	--	Dead stranding with an iron bolt imbedded in roof of the mouth causing distortion of the skull.	C. Ruckdeschel and C. R. Shoop pers. commun.
I-Cc-6	4/6/80-11/1/80	Cumberland Is., Georgia, U.S.A.	--	Seventeen of 43 guts (43%) examined from stranded turtles contained large amounts of ocean-dumped, man-caught food, including fish, shrimp carapaces, and squid remains. The intestines were often packed with fish bones. Likely sources of this food debris included unwanted catch from shrimp trawlers and discharge from seafood processors. Incidental feeding may cause an artificially large turtle population in the trawler impacted fishing area.	Shoop and Ruckdeschel 1982
I-Cc-7	11/78	Cape Canaveral, Florida, U.S.A.	82 kg	Live capture in trawl. Heavy monofilament fishing line protruding from mouth. 60-90 cm piece pulled out. Numerous encrusting organisms, primarily mussels, growing on line and partly digested. Presence of bile on swallowed portion suggested that the line had entered the small intestine.	L. Ogren pers. commun.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-8	1978	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small," 57 cm	Weathered petroleum (tar) sealed the mouths and nostrils. "27 small sea turtles of three species were handled," but the number of loggerheads was not stated. A 57-cm loggerhead was seen with a small amount of tar in its mouth, but appeared to be unaffected. See also Case I-Cm-18 and I-Ei-4.	Witham 1983.
I-Cc-9	1976-79	Texas, U.S.A.	--	Digestive tract of dead stranding contained pieces of a plastic bottle, as well as bird feathers and sargassum seaweed.	B. Fulls pers. commun. in Rabalais and Rabalais 1980.
I-Cc-10	Early 1970's	Mon Repos, Queensland, Australia	Adult, F	Stomachs of three turtles drowned in shrimp trawls in internesting habitat contained fish, shrimp, and cuttlefish. Though not suggested by the author, the apparent atypical nature of this food indicates it may have been unwanted catch discarded by trawl fishermen (compare with Case I-Cc-5).	Limpus 1973.
I-Cc-11	10/31/72	Hyogo Prefecture, Japan	S-30 cm	Plastic debris found in stomach. Had been released at Tokushima Prefecture 90 days earlier following captive rearing from a hatchling.	I. Uchida pers. commun.
I-Cc-12	5/19/75	Owase, Japan	S-69 cm, 35 kg, F	Transparent and blue plastic sheet found in stomach.	I. Uchida pers. commun.
I-Cc-13	6/75	Kushimoto, Japan	S-60 cm, 33 kg, F	Plastic debris found in stomach.	I. Uchida pers. commun.
I-Cc-14	9/29/80	Hyogo Prefecture, Japan	S-84 cm, 83 kg, F	Plastic debris found in stomach.	I. Uchida pers. commun.
I-Cc-15	5/14/84	Shimane Prefecture, Japan	S-33 cm	Plastic bag, piece of synthetic line, and domestic vegetables found in stomach. Had been released at Okinawa 50 days earlier following captive rearing from a hatchling.	I. Uchida pers. commun.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-16	12/29/78	Cocoa Beach, Florida, U.S.A.	S-73 cm, 54 kg	Found with 3 monofilament lines protruding from the mouth and cloaca. Lines were cut flush with the jaw and skin, and the turtle was kept in captivity. It floated abnormally at the surface and would not feed. After 6 weeks in this condition, it excreted 4.6 m (15 ft) of line. Thereafter, a dramatic change occurred in its behavior and it fed voraciously. It was released 1 month later on 3/14 weighing 48 kg. At the time the line was passed, it weighed 45 kg.	L. Ehrhart, T. Clabaugh, S. Gravel, and R. Witham pers. commun.
I-Cc-17	10/5/84	Chesapeake Bay, Virginia, U.S.A.	S-51 cm	Captured alive in a pound net and found to have the "half-round base of a plastic champagne cork stuck around the base of the lower left jaw." Turtle appeared healthy but had a small necrotic spot on the jaw beneath the cork.	J. A. Musick pers. commun.
I-Cc-18	1979-80	Madeira (lat. 32°45'N, long. 17°W)	S-27 to 52 cm	Three turtles purchased at Funchal were found to contain pieces of glass up to 4 cm long, pieces of plastic, nylon thread, and numerous small clots of oil throughout the digestive tract.	Van Nierop and Hartog 1984
I-Cc-19	6/4/81	Sao Miguel, Azores (lat. 37°33'N, long. 25°27'W)	S-26 cm	Purchased from fisherman. The caecum contained a piece of white paper 3 by 3 cm, 4 pieces of nylon thread 1-3 cm, a ball of thread 4 by 1 by 1 cm, 6 pieces of polyethylene 1 by 1 by 0.5 cm, and clots of oils throughout the digestive tract.	Van Nierop and Hartog 1984
I-Cc-20	5/25/80	Selvagen Grande (lat. 30°09'N, long. 15°52'W)	S-22 cm, F	Caught 1 mile offshore. Gut contained a piece of nylon thread 5 cm long, 5 pieces of firm transparent plastic up to 1 cm long, and clots of oil dispersed throughout the tract.	Van Nierop and Hartog 1984

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
			Eretmochelys imbricata, hawksbill turtle		
I-Ei-1	--	Ascension Is.	--	Invertebrate fauna "appears to be extremely lean, and there is little submerged vegetation of any kind. This may account for the peculiarly scrawny look of Ascension hawksbills, and also may explain their observed tendency to group about any refuse that is dumped in shore waters."	Carr and Stancyk 1975
I-Ei-2	1970-72 (July-October)	Tortuguero Bank, Costa Rica	Adults, 2 F, 2 M	Four out of 20 stomachs (20%) containing food were found to have plastic and other man-made litter. "A compacted ball of well-chewed sheet plastic" was present in one of the stomachs.	Carr and Stancyk 1975, cited in Witzell 1983.
I-Ei-3	10/22/78	Selvagen Pequena, eastern Atlantic (lat. 30°2'N, long. 16°1'W)	36 cm, M	"Colon and rectum appeared to contain a variety of man-made litter, viz., 15 pieces of hard plastic (two orange coloured, the rest white; largest piece measuring about 28 by 20 by 3 mm) and several thin membranaceous fragments (one yellow, one black, rest whitish or transparent)." Turtle taken from "bay on east coast."	Hartog 1980, cited in Witzell 1983.
I-Ei-4	1978-79	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small"	Weathered petroleum (tar) sealed the mouths and nostrils. "27 small sea turtles of three species were handled," but the number of hawksbills was not stated. See also Case I-Cm-18 and I-Cc-8.	Witham 1983.
I-Ei-5	1/16/81	Jupiter Island, Florida, U.S.A.	S-21 cm, F	Emaciated beach stranding with styrofoam precursor (plastic bead) and paper in digestive tract. Injury to front flipper.	Meylan 1984.
I-Ei-6	2/81	Ft. Lauderdale, Florida, U.S.A.	S-14 cm, F	Emaciated beach stranding with plastic particles and tar droplets in digestive tract.	Meylan 1984.
I-Ei-7	2/16/81	Jensen Beach, Florida, U.S.A.	S-14 cm	Beach stranding with styrofoam precursors in digestive tract. Tar present on head and throughout digestive tract.	Meylan 1984.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Ei-8	2/16/81-2/17/81	Hutchinson Is., Florida, U.S.A. (lat. 17°17'N, long. 80°13'W)	10 cm, 15 cm	Two turtles found alive with tar in mouth and around head. One died the next day.	Anonymous 1981a.
I-Ei-9	6/23/82	Big Pine Key, Florida, U.S.A. (lat. 24°39'N, long. 81°19'W)	18 cm	Stranding with tar in mouth and covering body. Cleaned and released.	Klett 1982.
I-Ei-10	7/13/83	Hutchinson Is., Florida, U.S.A.	S-20 cm	Beach stranding with styrofoam, plastic sheet, plastic particles and tar droplets in digestive tract. Carapace and limbs coated with tar. Nostrils and mouth sealed.	Meylan 1984.
I-Ei-11	10/15/84	Kahana Bay, Oahu, Hawaii	S-36 cm, 5.4 kg	Died 2 days after stranding in an emaciated condition. Left front flipper completely amputated but healed. Gooseneck barnacles on carapace suggested a pelagic existence. Large pocket of numerous plastic particles and semi-hard fecal matter found at midpoint of intestine. Intestinal wall had expanded into stomachlike compartment. Plastic and fecal matter mass weighed 780 g.	G. Balazs unpubl. data.
			<u>Dermochelys coriacea</u>, leatherback turtle		
I-Dc-1	8/4/68	Ameland Is., Netherlands	158 cm, 485 kg, F	Dead stranding with piece of plastic in the gut.	Brongersma 1969, 1972.
I-Dc-2	7/7/70	Ramsgate, Natal, South Africa	C-160 cm, 340 kg, F	Dead stranding. "Duodenal tract completely filled by a sheet of heavy plastic measuring 3 by 4 m when spread out. The sheet was so tightly packed that considerable force was required to open it initially, and it must have had a serious effect on the passage of food from the stomach. Whether a complete blockage had been effected was difficult to ascertain because there was pink fluid in the lower gut." 697 well-developed eggs present.	Hughes 1974a.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-3	7/29/71	Cornwall, England	C-142 cm, 224 kg, F	Small plastic bags found in the stomach and posterior gut. Turtle had become entangled in the lines of lobster pots.	Brongersma 1972; Hartog and Van Nierop 1984.
I-Dc-4	7/30/77	Hyogo Prefecture, Seto Sea, Japan	S-120 cm	A 60 by 70 cm piece of twisted vinyl fiber was pulled from the cloaca after a 5 cm piece became visible. The turtle had been entangled 10 days earlier in a gill net. Died the following day.	I. Uchida pers. commun.
I-Dc-5	9/22/80	Smith Point State Park, New York, U.S.A. (lat. 40°45'N, long. 72°48'W)	183 cm	Badly decomposed. Had ca. 180 m of heavy duty nylon fishing line in the gastrointestinal tract, with leading piece extending from the mouth.	Sadove 1980.
I-Dc-6	10/22/81	Beach Haven, New Jersey, U.S.A. (lat. 39°33'33"N, long. 74°14'10"W)	150 cm, F	Fresh dead stranding. "Large number of plastic bags in posterior stomach and extending 13 cm into intestine; claylike mass blocking intestinal valves."	Schoelkopf 1981.
I-Dc-7	Summer 1982	Long Island, New York, U.S.A.	--	Eleven out of 15 leatherbacks (73%) that washed ashore during a 2-week period had plastic bags "totally blocking their stomach openings." Ten of the beached turtles had four to eight quart-sized bags in their stomachs. One had eaten 15. Turtles have been seen swimming around transparent bags in the ocean with their mouths open, as if they thought the discarded plastic was their favorite meal. The turtles found were too badly decomposed for full autopsies, but "the plastic bags either contributed to the cause of death or may have been the cause of death." (All information was provided by Samuel Sadove, see also Sadove[3].)	Anonymous 1983b.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-8	1980-84	New York Bight, U.S.A.	--	"Of a total of 42 sea turtle strandings reported since 1980, almost 50% of these animals contained significant amounts of plastic in their stomachs. One animal had 15 quart-size clear plastic bags in its stomach. Although death from plastic ingestion could only be determined for four animals, it is possible that a number of animals' demise or susceptibility to injury causing death could be the result of stress from partial blockage caused by the plastic."	Sadove[3].
I-Dc-9	1979-80	Pucusana, Depto. Lima, Peru	--	Plastic bags and film were noted in intestinal tracts of 19 of 140 specimens (13%) examined. All cases involved sizable pieces of plastic. The plastic was within the lumen of the digestive tract and in a twisted, elongate form suggesting peristaltic transport.	Fritts 1982.
I-Dc-10	1970-80	Worldwide	--	Evidence showing that ingestion of plastic is common; 7 out of 16 stomachs (44%) contained plastic or cellophane. Turtles are different from those quantitatively summarized by Fritts (1982) and Sadove (see footnote 3).	Mrosovsky 1981.
I-Dc-11	--	--	--	Large amounts of plastic commonly occur in the intestines.	J. Frazier personal observations in Eisenberg and Frazier 1983.
I-Dc-12	--	Coast of France	--	Seven out of eight (87.5%) turtles had swallowed plastic.	Duron and Duron 1980.
I-Dc-13	1980	Coast of France	--	Plastic bags were found in the stomachs of 2 of the 3 dead stranded turtles examined.	Duguy and Duron 1981.
I-Dc-14	1981	Coast of France	C-160 cm, M C-152 cm, M	Plastic bags were found in the stomachs of 2 of the 3 dead stranded turtles examined.	Duguy and Duron 1982.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-15	6/10/79	Coast of France	C-160 cm, F	Dead stranding with plastic bags in the stomach that appear to cause a blockage to the movement of food.	Duguy et al. 1980; Duguy 1983.
I-Dc-16	1980-84	Massachusetts, U.S.A.	--	Of 9 dead strandings examined over a 5-year period, 4 contained plastic. Two had balls of accumulated plastic in the upper part of the colon, and 2 had pieces of plastic in the esophagus. One of the latter cases involved a small piece of a plastic bag and the plastic-coated label from a prescription bottle of medication.	R. Prescott and N. Frazer pers. commun.
I-Dc-17	10/17/83	Chesapeake Bay, Virginia, U.S.A.	C-130 cm	Bloated stranding that was found to have a "plastic wrapper from a ketchup packet in its intestine."	J. A. Musick pers. commun.
I-Dc-18	1979-80	Bay of Plenty, New Zealand	Adult	Died shortly after beaching itself. Necropsy revealed the esophagus to be "packed with polythene bread bags."	Cawthorn 1985.
I-Dc-19	9/7/80	Scilly Isles, England	Est. 500 kg, M	Caught alive in the lines of a lobster pot. Pylorus of stomach was "more or less blocked by a ball of compressed plastic composed of a transparent plastic bag 15 by 17 cm, a frayed sheet of white plastic and many small shreds 0.4-4 cm."	Hartog and Van Nierop 1984.
I-Dc-20	8/4/81	Terschelling Is., Netherlands	510 kg, M	Caught alive at sea, but died aboard the vessel. Stomach contained a "well-preserved plastic bag 13.5 by 17.5 cm." A small bird feather was found in the intestine.	Hartog and Van Nierop 1984.
				<u>Lepidochelys kempi</u>, Kemp's ridley turtle	
I-Lk-1	6/27/82	Ft. Lauderdale, Florida, U.S.A.	23 cm	Tar in mouth and covering body. Taken for treatment.	Fletemeyer 1982.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Lk-2	1980's	Padre Island, Texas, U.S.A.	Immature	When large numbers of captive-reared yearlings have been released, there are sometimes a few that wash up on the beach during the following week. Many of these appear to have eaten tar balls, as indicated by tar on their beak and mandible. A few of the stranded turtles are dead, but most appear to be healthy when cleaned up and re-released. Also, a milk carton was found to have been ingested by a turtle stranded a year after being released.	T. Wibbels pers. commun.; Anonymous 1983c.
I-Lk-3	1980's	Texas, U.S.A.	—	Out of a number of stranded turtles necropsies, two were found to have debris in the gut. One had "parts of a beer can" and the other contained a plastic bag.	D. Owens pers. commun.

[1] FFS = French Frigate Shoals; NWHI = Northwestern Hawaiian Islands.
[2] C = curved; S = straight.
[3] S. Sadove, Okeanos Ocean Research Foundation, P. O. Box 776, Hampton Bay, N.Y. 11946, unpubl. rep., 1984, 2 p.

Table 2.--Worldwide records of marine turtles entangled in oceanic debris

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
				Chelonia mydas, green turtle	
E-Cm-1	--	Tortuguero, Costa Rica	Adults, F	Several times over the years nesting turtles have come ashore with monofilament line wrapped around a flipper, sometimes so tight there was considerable tissue necrosis. Loss of limb predicted if the line had not been removed. No cases have been published.	K. Bjorndal and A. Carr pers. commun.
E-Cm-2	1982	Bundaberg, Queensland, Australia	"Subadult"	"Washed in dead tangled in rope with a light reef anchor attached. Origin and purpose of anchor undetermined."	C. Limpus pers. commun.
E-Cm-3	7/30/84	San Gabriel California, U.S.A.	Est. 90 kg	Reported to be seen with fishing line entangled around the tail and a long piece of wood.	H. S. Stone unpubl. data.
E-Cm-4	6/29/74	East Is., FFS, NWHI	Adult, F	Synthetic line and large float found entangled around the neck of a turtle coming ashore to nest.	G. Balazs unpubl. data.
E-Cm-5	5/19/80	Trig Is., FFS, NWHI	Adult, F	Large piece of synthetic trawl net found entangled around the neck of a turtle lying motionless on a nesting beach. Net cut free and turtle released in apparently good health.	G. Balazs unpubl. data.
E-Cm-6	9/80	East Is., FFS, NWHI	S-5 cm	Dead hatchling found on land with right front flipper entangled in strip of cloth debris.	J. Andre pers. commun.
E-Cm-7	4/8/82	Lisianski Is., NWHI	S-43 cm	Left front flipper entangled in large piece of synthetic net snagged on reef flat close to shore. Necrosis at site of constriction. Turtle tagged and released.	Henderson 1984.
E-Cm-8	5/82	Midway, NWHI	C-36 cm	Found dead floating nearshore entangled in a piece of blue synthetic net. Deep cut in right front flipper.	G. Balazs unpubl. data.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Cm-9	6/18/82	Whale-Skate, FFS, NWHI	Adult, M	Rib bones and metal flipper tag found entangled in a scrap of synthetic trawl net washed ashore.	J. Andre pers. commun.; Balazs 1983a.
E-Cm-10	6/30/84	Tern Is., FFS, NWHI	Adult, M	Stranding with neck and left front flipper entangled in long piece of blue synthetic rope. Deep flipper abrasion from line. Rope snarl was also entangled in anchor line of lobster larvae collector which came ashore with the turtle. Tumors present.	J. R. Henderson pers. commun.
E-Cm-11	6/7/84	Trig Is., FFS, NWHI	Adult, M	Heavy monofilament fishing line tightly entangled around left front flipper producing a deep cut. Line removed and turtle released.	G. Balazs unpubl. data.
E-Cm-12	12/76	Oahu, Hawaii	C-34 cm	Found severely emaciated and entangled in rope. Died within a few days.	R. Bourke pers. commun.
E-Cm-13	8/3/77	Waimanalo Bay, Oahu, Hawaii	C-44 cm	Portion of a plastic container stuck tightly around turtle's neck. Object sawed-off and the turtle released in apparently good condition.	Balazs 1980.
E-Cm-14	1/23/78	Punaluu, Kau, Hawaii	S-57 cm	Hand captured while scuba diving. Monofilament fishing line wrapped tightly about right front flipper producing deep wound. Turtle tagged and released after cutting out line. Injury completely healed when recaptured 6 years later at same location.	G. Balazs and A. Kam unpubl. data.
E-Cm-15	6/79	Maunalua Bay, Oahu, Hawaii	S-47 cm	Drowned turtle with right front flipper tangled in monofilament fishing line snagged on the bottom.	J. Rutka pers. commun.
E-Cm-16	4/81	Oahu, Hawaii	--	Entangled in a piece of synthetic green trawl net floating offshore; turtle released alive.	S. Kaiser and L. Aguiar pers. commun.; Balazs 1982b.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Cm-17	6/19/81	Kailua Bay, Oahu, Hawaii (lat. 21°24'N, long. 157°43'48"W)	C-64 cm	Entangled in rope attached to an abandoned anchor. One turtle dead, the other very weak--treated and released.	Mooney and Naughton 1981.
E-Cm-18	2/83	Kawainui marsh, Oahu, Hawaii	S-43 cm	Found entangled in "kite string" in a lethargic condition. Died in captivity a few days later.	P. Burnett pers. commun.
E-Cm-19	6/23/83	Malaekahana, Oahu, Hawaii	--	Decomposing carcass washed ashore with synthetic netting and line imbedded in the neck.	D. Eckert pers. commun.
E-Cm-20	1/10/84	Kailua-Kona, Hawaii	C-85 cm, F	Found resting on the bottom in a small boat harbor. Large quantity of monofilament fishing line wrapped tightly around right front flipper. Large tumors also present.	K. Spinney, P. Hendricks, K. McCoy pers. commun.
E-Cm-21	8/30/84	Kiholo, Hawaii	S-66 cm	Hand captured while snorkeling. Monofilament fishing line wrapped around right front flipper producing wound. Line removed and turtle released.	G. Balazs and A. Kam unpubl. data.
E-Cm-22	7/28/79	Texas, U.S.A.	Juvenile	Found with a fishing line wrapped around its flipper. The flipper was gangrenous and had to be amputated. "Young juveniles seem to have a propensity for becoming entangled in fishing line."	Hildebrand 1980.
E-Cm-23	6/24/81	Boca Raton, Florida, U.S.A. (lat. 26°23'N, long. 80°04'W)	19 cm	Found alive with "fishing line around right front flipper" which had "cut into bone."	Anonymous 1981c.
E-Cm-24	10/8/84	Kahului, Maui, Hawaii	Est. 46 kg	Front flipper tangled in buoy line of derelict, bottom fouled gill net. Turtle swam off with a piece of the line still attached to it.	F. Ball pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Cm-25	ca. 1980	Johnston Atoll (lat. 16°45'N, long. 169°31'W)	—	Large dead turtle found "tangled in a Japanese fish net" washed up near East Peninsula of Sand Island.	Balazs in press.
			Caretta caretta, loggerhead turtle		
E-Cc-1	5/29/78	Panama City, Florida, U.S.A.	C-84 cm, F	Fresh dead; found by scuba diver entangled in monofilament fishing line at "Warsaw Hole" 4 miles offshore at depths of 23-24 m (75-80 ft). Line fouled in limestone reef outcrop. Death presumed to be from drowning.	L. Ogren pers. commun.
E-Cc-2	1979	Panama City, Florida, U.S.A.	Subadult	Skeletal remains found on the beach. Humerus encircled with heavy monofilament fishing line twisted numerous times.	L. Ogren pers. commun.
E-Cc-3	6/30/84	Ponce Inlet, North Channel, Florida, U.S.A.	C-27.6 cm, 2.8 kg	"Caught and drowned in an abandoned gill net that had washed up on a rock jetty at the mouth of the inlet."	L. M. Ehrhart pers. commun.
E-Cc-4	1980-83	Barbuda, Leeward Is., Lesser Antilles (lat. 17°40'S, long. 61°50'W)	—	On several occasions a fisherman found loggerheads floating at sea entangled in pieces of netting. Sightings were believed to be associated with Japanese fishing boats in the area. Believed that the entangled turtles had been cut loose from trawls and left to drift.	Meylan 1983.
E-Cc-5	>1974	Cumberland Is., Georgia, U.S.A.	—	Dead stranding entangled in rope. Growth of a flipper was stunted due to constriction.	C. Ruckdeschel and C. R. Shoop pers. commun.
E-Cc-6	7/28/82	Hutchinson Is. Florida, U.S.A.	C-70 cm	"Foreflippers entangled in line and netting."	J. R. Wilcox pers. commun.
E-Cc-7	8.24/84	East Florida, U.S.A.	S-65 cm 37 kg	Left front flipper nearly severed by piece of monofilament line. Injured limb was amputated and the wound sutured prior to tagging (No. AAH-724) and release.	R. Witham pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
				Eretmochelys imbricata, hawksbill turtle	
E-Ei-1	8/14/77	Kaneohe Bay, Oahu, Hawaii	S-76 cm, F	Found entangled and decomposing in a lost but intact 183 m (600-ft) long monofilament gill net.	Balazs 1978.
E-Ei-2	4/13/82	Palm Beach, Florida, U.S.A. (lat. 26°40'N, long. 80°02'W)	15 cm	Found entangled in fish net by surfers. Taken for treatments where it recovered but "damaged flipper dropped off."	Fletcher 1982.
E-Ei-3	4/24/82	Delray Beach, Florida, U.S.A. (lat. 26°30'N, long. 80°03'30"W)	20 cm	Washed up in surf alive covered with tar and entangled in fishing line.	Wolf 1982.
E-Ei-4	6/11/82	Rock Harbor, Florida, U.S.A. (lat. 25°05'N, long. 80°27'W)	15 cm	Found alive with monofilament line wrapped around left front flipper, causing edema of limb.	Broadrick 1982.
E-Ei-5	7/14/83	Melbourne Beach, Florida, U.S.A.	S-19.5 cm, 0.9 kg	Found stranded in a weakened condition entangled in a 1-m length of braided synthetic rope 1.3 cm in diameter. Unraveled strands at the rope end were tightly bound around the base of the left front flipper. A "flat metal clip" deeply imbedded in the flesh held the line in place. A heavy mass of sargassum was also caught in the tangled rope. The turtle was held in captivity for 2 months where it recuperated, but lost its necrotic flipper.	Redfoot et al.[3]
E-Ei-6	5/25/77	Texas, U.S.A.	Juvenile	Found with line wrapped around a front flipper that developed gangrene and had to be amputated.	Hildebrand 1980.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Ei-7	1/78	Texas, U.S.A.	Juvenile	Found with a fishing line "wrapped around the upper body." Line was caught on an obstruction and apparently the turtle had been on a tether for a considerable time. "Although emaciated, the animal was healthy. A large number of oysters had settled under the raised edges of the scutes."	Hildebrand 1980.
E-Ei-8	8/9/83	Port Aransas, Texas, U.S.A. (lat. 27°50.3'N, long. 97°03.1'W)	C-29 cm	Found with a "piece of plastic onion bag" entangled around neck. "Abraded a groove in neck, but no infection was present." Turtle held in captivity, then tagged and released on 9/3/83 near an offshore oil rig.	A. F. Amos pers. commun.
E-Ei-9	12/20/83	Port Aransas, Texas, U.S.A. (lat. 27°50'N, long. 97°03'W)	C-25 cm	Found entangled in monofilament fishing line in a boat basin with 6.5°C seawater. Severe constriction to left front flipper. Turtle revived after being warmed up, but died 3 days later.	A. F. Amos pers. commun.
			Lepidochelys olivacea, olive ridley turtle		
E-Lo-1	3/73-6/73	Eastern Pacific (ca. lat. 2°-10°N, long. 85°-97°W)	---	Shipwrecked sailors adrift in a rubber raft occasionally had turtles become entangled in the ropes securing their drogue. Turtles were an important food source for survival.	Bailey and Bailey 1974.
E-Lo-2	7/20/81	Kailua-Kona, Hawaii	C-78 cm, F	Entangled in a large piece of synthetic trawl net floating several miles offshore. Turtle was tagged and released in good condition.	P. Hoogs and L. Ahlo pers. commun.; Balazs 1982b.
E-Lo-3	11/28/81	Pukoo, Molokai, Hawaii	S-22 cm	Washed ashore entangled in synthetic line. Deep cuts from the line present on three flippers. Turtle moderately emaciated, but successfully rehabilitated at the Waikiki Aquarium.	Afelin and Puleloa 1982; Balazs 1982b.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Lo-4	7/29/82	Oahu, Hawaii	S-38 cm	Entangled in a piece of green synthetic net floating 6-7 miles offshore. Turtle tagged and released in good condition.	S. Henderson pers. commun.
E-Lo-5	5/19/83	Hana, Maui, Hawaii	C-62 cm	Entangled in a 1.5 m^2 piece of green, synthetic net floating 1 mile offshore. Rehabilitated, tagged, and released.	E. Merrill pers. commun.
E-Lo-6	1980-84	Pacific coast of Costa Rica	Adults, F	A few turtles (3-4) found with "short pieces of monofilament and nylon webbing wrapped around limbs." One had a flipper totally paralyzed from webbing. Great numbers of nesting olive ridleys have been examined over the past 5 years, but only these few have been found entangled.	S. Cornelius pers. commun.
			Dermochelys coriacea, leatherback turtle		
E-Dc-1	8/8/67	Bermuda	150 cm "head to tail," est. 500 kg.	"Tangled in a fishing net and drifting helplessly."	D. B. Wingate cited in Lee and Palmer 1981.
E-Dc-2	8/79	North central Pacific (lat. 41°N, long. 178°W)	Adult	Observed swimming at the surface trailing a piece of rope.	G. Naftel pers. commun.
E-Dc-3	1980	North central Pacific (lat. 35°-45°N, east of long. 170°E)	Adult	At least five dead turtles seen floating at the surface entangled in pieces of monofilament squid net. Probably cut adrift by Japanese or Taiwanese fishermen.	J. Ray pers. commun.; Balazs 1982.
E-Dc-4	12/82	Kailua-Kona (OTEC buoy), Hawaii	682 kg, F	Entangled at night 2 miles offshore in a "parachute anchor." Turtle reportedly dragged a boat around for several hours before being killed. Carcass brought in and weighed on a scale to within 10 kg.	Anonymous telephone calls to G. Balazs.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Dc-5	6/16/81	Watch Hill, New York, U.S.A. (lat. 40°43'43"N, long. 72°52'56"W)	157 cm, M	Found dead, "tied up in rope" in an advanced state of decomposition.	Sadove and Smith 1981.
E-Dc-6	1982-84	Rhode Island, U.S.A.	---	Dead stranding; a rope with longline fish hook imbedded in a flipper.	C. R. Shoop pers. commun.
E-Dc-7	8/1/84	Cape Town, South Africa	Adult	Came ashore with a piece of nylon rope around a foreflipper. Wound caused by rope appeared to have healed, but there was a huge weight of *Mytilus* mussels and gooseneck barnacles growing on the rope.	G. R. Hughes and R. Rau pers. commun.
E-Dc-8	11/18/79	Saint-Clement-des-Baleines, France	C-157 cm, M	Dead stranding; nylon line snarled around decomposing remains of left front flipper.	Duguy 1983.
				Species unknown	
E-Un-1	8/79	Eastern Mediterranean	"Small"	Turtle seen at the surface attempting to swim with a large piece of what appeared to be plastic sheet wrapped around its shell.	Morris 1980a.
E-Un-2	8/82	Oahu, Hawaii	Subadult	Vertebrae and ribs of sea turtle found tightly entangled in a piece of trawl net floating about 10 miles offshore.	J. Naughton pers. commun.
E-Un-3	5/82	West Molokai, Hawaii	---	Entangled in a piece of green synthetic trawl net floating offshore.	S. Kaiser and L. Aguiar pers. commun.
E-Un-4	1/1/84	Waianae Harbor, Oahu, Hawaii	Est. 45 kg	Observed swimming entangled in a piece of brown net. Seen by others at different times at the same location. Likely to have been a green turtle.	A. Endo and P. Conant pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Un-5	5/84	High seas southwest of Hawaii	--	Turtle entangled in fishing line seen floating at the surface by personnel of the NOAA ship *Townsend Cromwell*.	B. Burch pers. commun.

[1]FFS = French Frigate Shoals; NWHI = Northwestern Hawaiian Islands.
[2]C = curved; S = straight.
[3]W. E. Redfoot, L. M. Ehrhart, and P. W. Raymond. A juvenile Atlantic hawksbill turtle, *Eretmochelys imbricata*, from Brevard County, Florida. Manuscr. in prep. Seminole Community College, Sanford, FL 32771.

least 160 turtles. The remaining cases (8%) describe instances of turtles seen foraging on debris, but the actual numbers were not given. Except for this latter category and Case I-Cm-12 and I-Dc-4, all accounts of debris ingestion were derived from stranded turtles (74%) or turtles taken by fishermen (26%), where the mouth, or some portion of the gastrointestinal contents, had been examined. Most of the stranding cases (84%) involved dead animals. Case I-Cm-12 and I-Dc-4 dealt with the removal of plastic sheets from the cloacae of live turtles.

Cases of debris entanglement shown in Table 2 almost exclusively (92%) involved single turtles. Slightly more than half came from strandings, and the remainder from chance sightings at sea. Only 38% of the entangled turtles were dead or later died. Many more would undoubtedly have died in the absence of human intervention.

It is apparent that strandings represent a principal source of information on debris ingestion and entanglement. A stranded turtle, to be of scientific worth, must be found by someone who properly reports it before it washes or swims away, becomes covered with sand, or decomposes completely. Even when a prompt and accurate report has been made, it is likely that a carcass showing advanced decay would not be cut open and inspected for ingested contents as often as a fresh specimen. A further constraint to collecting data on debris ingestion and entanglement is that most turtles dying in the water probably do not stay afloat long enough to reach shore. This would be especially true for those turtles living on or migrating through the high seas.

Several reports that were located or received were significant for their absence of findings relevant to debris ingestion and entanglement. Mortimer (1981) found no signs of synthetic debris in the stomach contents of 243 green turtles taken in a fishery off the Caribbean coast of Nicaragua. At Cumberland Island, Georgia (U.S.A.), more than 600 dead stranded loggerheads have been cataloged between 1974 and 1984. Gastrointestinal contents were examined in many of these turtles. No plastics or other debris were seen, except for an iron bolt in the roof of one turtle's mouth and a fishhook in the small intestine of another (C. Ruckdeschel and C. R. Shoop pers. commun.). Also, only a single instance of entanglement (E-Cc-5, Table 2) was found among these 600 strandings. At Little Cumberland Island, Georgia, no entanglement in debris has been recorded in stranded or nesting loggerheads monitored since the early 1960's (J. I. Richardson pers. commun.). Only two cases of plastic ingestion have been found in hundreds of turtles (loggerhead, Kemp's ridley, and leatherback) examined during recent summers in Virginia, Maryland, and Delaware (J. A. Musick pers. commun.).

Geographic Distribution

Reports on debris ingestion originated from 19 worldwide locations, and those on debris entanglement came from 10 (Table 3). The coastal continental U.S. accounted for a large portion of debris ingestion (40.8%) and entanglement (31.7%). An established reporting network in the region undoubtedly influenced the outcome. Hawaii, which is listed separately in Table 3, accounted for 46.7% of entanglement cases. This was due to first-hand reports compiled by the author. If better coverage could be achieved, a similar increase would likely be experienced at certain other locales.

Table 3.--Geographic distribution of known cases of debris ingestion and entanglement by marine turtles.

Location	Percent cases reported in this paper	
	Ingestion	Entanglement
Azores	1.3	--
Ascension Island	2.6	--
Australia	2.6	1.7
Balearic Islands	1.3	--
Bermuda	--	1.7
Costa Rica	3.9	3.3
England	2.6	--
France	5.3	1.7
French Polynesia	1.3	--
Hawaii (U.S.A.)	9.2	46.7
Japan	10.5	--
Johnston Atoll	--	1.7
Lesser Antilles	--	1.7
Marshall Islands	1.3	--
Madeira (Portugal)	2.6	--
Mediterranean (eastern)	--	1.7
Netherlands	2.6	--
New Zealand	1.3	--
Pacific Ocean (high seas)	--	6.7
Peru	2.6	--
Selvagen Islands	2.6	--
South Africa	3.9	1.7
Tokelau	1.3	--
United States (mainland)	40.8	31.7

Debris Ingestion

Debris was ingested by five species of sea turtles (Table 4). The green turtle was the most commonly documented (32%), followed by the loggerhead (26%), leatherback (24%), and hawksbill (14%). Only a small number of reports on Kemp's ridley was obtained (4%). No reports were located for the olive ridley or flatback. In four of the five species found to eat debris, immature turtles were more frequently involved than adults (Table 5). This could be due to the greater proportion of immature turtles expected in the population, or a greater tendency for immature turtles to feed on floating debris. The leatherback alone contrasted sharply with this pattern; only adults ingested debris. Immature leatherbacks, especially juveniles, are rarely seen anywhere.

The various types of ingested debris were grouped into 14 categories (Table 4). Plastic bags and sheet were the most prevalent material (32.1%), followed by tar balls (20.8%), and plastic particles (18.9%). Some of the more unusual, but less frequently reported, items consisted of cloth, fishing net, paper, glass, and metal. Pieces of synthetic rope and

Table 4.--Percent occurrence of types of debris found ingested by marine turtles. (Compiled from data listed in Table 1 where many cases involve turtles that ingested two or more types of debris.)

Species	Plastic bags and sheets	Plastic and styrofoam particles	Tar	Kitchen scraps	Synthetic line and thread	Monofilament fishing line	Cloth	Fishery by-catch	Net	Paper	Glass	Metal	No. of cases from Table 1
Green turtle	25.8	6.5	32.3	9.7	12.9	3.2	6.5	--	3.2	--	--	--	25
Loggerhead	14.7	32.4	11.8	5.9	11.8	5.9	--	5.9	--	2.9	5.9	2.9	20
Hawksbill	16.7	38.9	33.3	5.5	--	--	--	--	--	5.5	--	--	11
Leatherback	94.4	--	--	--	--	5.6	--	--	--	--	--	--	19
Kemp's ridley	20.0	--	40.0	--	--	--	--	--	--	20.0	--	20.0	3
All species	32.1	18.9	20.8	5.7	7.5	3.8	1.9	1.9	1.0	2.8	1.9	1.9	78

Table 5.--Age composition of marine turtles ingesting and becoming entangled in debris.

Species	Percent composition from cases reported in this paper: Adult	Immature	Sample size N
	Ingestion		
Green turtle	19.0	81.0	21
Loggerhead	18.7	81.3	15
Hawksbill	9.0	90.9	11
Leatherback	100.0	0	11
Kemp's ridley	0	100	3
All species	30.6	69.4	62
	Entanglement		
Green turtle	41.7	58.3	24
Loggerhead	0	100	4
Hawksbill	11.1	88.9	9
Olive ridley	50.0	50.0	4
Leatherback	100.0	0	7
All species	41.7	58.3	48

monofilament line showed up in the digestive tracts of green, loggerhead, and leatherback turtles under conditions that did not seem to involve swallowing a baited hook. Another interesting aspect shown in Table 4 is the ingestion by loggerheads of unwanted fishery by-catch jettisoned from shrimp trawlers.

Quantitative data of debris ingestion were available in 16 of the cases covering 4 species (Table 6). Various plastics were again the most prevalent items, ranging from 6 to 87% occurrence in the turtles sampled. Noteworthy among these were Case I-Dc-9 where 13% of 140 leatherbacks examined had eaten plastic bags, Case I-Cm-4 where 23% of 39 green turtles contained plastic bags, and Case I-Cc-6 where 43% of 43 dead stranded loggerheads contained discarded fishery by-catch.

Debris Entanglement

Five species of sea turtles were involved in entanglement with debris (Table 7). Species identification was not possible in 5 of the 60 cases. The green turtle accounted for 42% of all cases; no records were located for Kemp's ridley or the flatback. Immature turtles were entangled more frequently than adults, but the pattern was not as pronounced as in debris ingestion (Table 5). Again, only adult leatherbacks were found entangled.

The debris responsible for entanglement was grouped into nine categories (Table 7). Monofilament fishing line accounted for 33.3% of all

Table 6.--Quantitative reports cited in this paper of debris found ingested by marine turtles.

Species	Sample size N	Type of debris	Percent with debris	Case No. in Table 1
Green turtle	11	Plastic	37	I-Cm-2
	11	Cloth	18	I-Cm-2
	39	Plastic bags	23	I-Cm-4
Loggerhead	32	Plastic beads	6	I-Cc-2
	32	Plastic sheet	6	I-Cc-2
	9	Plastic and glass	44	I-Cc-3
	43	Fishery by-catch	43	I-Cc-6
	3	Plastic, glass, and thread	100	I-Cc-18
Hawksbill	20	Plastic and other synthetic litter	20	I-Ei-2
Leatherback	42	Plastic bags	50	I-Dc-8
	140	Plastic bags	13	I-Dc-9
	16	Plastic	44	I-Dc-10
	8	Plastic	87	I-Dc-12
	3	Plastic bags	33	I-Dc-13
	3	Plastic bags	33	I-DC-14
	9	Plastic	44	I-Dc-16

Table 7.--Percent occurrence of types of debris found entangled on marine turtles. (Compiled from data listed in Table 2 where each case was considered to involve only a single type of entangling debris.)

Species	Monofilament fishing line	Rope	Trawl net	Monofilament net	Plastic object	Plastic sheet or bag	Line with hook	Cloth	Parachute anchor
Green turtle (N = 25)	36.0	24.0	24.0	8.0	4.0	--	--	4.0	--
Loggerhead (N = 7)	57.1	28.6	--	14.3	--	--	--	--	--
Hawksbill (N = 9)	55.6	1.1	--	22.2	--	11.1	--	--	--
Olive ridley (N = 6)	--	33.3	50.0	16.7	--	--	--	--	--
Leatherback (N = 8)	12.5	37.5	--	25.0	--	--	12.5	--	12.5
Unknown species (N = 5)	20.0	--	60.0	--	--	20.0	--	--	--
All species (N = 60)	33.3	23.3	20.0	13.3	1.7	3.3	1.7	1.7	1.7

cases. Some of these could have resulted from encounters with tended fishing gear. However, none of the reports appearing in this category mentions a fishhook attached to monofilament line, or hooked into the turtle. For several cases (E-Cm-15, I-Cc-1, and E-Ei-7), it is evident that turtles had become entangled in lost pieces of line snagged on the bottom.

Other major categories of debris found on turtles included segments o snarls of rope (23.3%), pieces of trawl webbing (20.0%), and monofilament net (13.3%). Fishing-related debris was involved in 68.3% of all cases. The category of "rope" is not included in this figure, even though a fair amount of rope debris probably does come from fishing efforts.

DISCUSSION

Impacts of Ingested Debris

Sea turtles occasionally consume naturally occurring debris such as bird feathers, terrestrial vegetation, bottom substrate, and pumice. In this paper it has been well documented that they may also eat all sorts of man-related litter. However, in most instances the actual impact of this material is unclear in terms of mortality or morbidity. Certainly the adverse effects of tar balls and oil droplets can be readily perceived wher a turtle's jaws become stuck together, throats are packed with tar, and toxic hydrocarbons are transported across the gut wall. As for plastic bags and sheets being eaten, the available evidence for direct harm or mortality is much less conclusive. Seven of the strandings presented in Table 1 describe the ingestion of plastics in quantities large enough or compacted in such a manner to have definitely caused blockage (Cases I-Cm-25, I-Ei-11, I-Cc-16, I-Dc-2, I-Dc-8, I-Dc-15, and I-Dc-18). In contrast, some reports documenting ingestion of plastics deal with seemingly healthy turtles caught by fishermen (Case I-Cm-4, I-Cm-15, I-Ei-2, and I-Dc-90). The twisted configuration of the plastic found throughout the intestines in several turtles suggests that such material can be moved along and voided naturally by peristaltic transport. In Case I-Dc-4, the twisted tip of a plastic sheet was seen protruding from the cloaca of a large leatherback accidentally caught alive in a net. A similar condition was observed in a juvenile green turtle raised in captivity (Case I-Cm-12). However, in both cases, the plastic was pulled out manually by researchers before they discerned whether it would have been expelled naturally.

Even if there is no direct mechanical blockage, there are still potentially serious problems such as lost nutrition, reduced absorption of nutrients while the plastic lines the gut wall, and absorption of toxic plasticizers (PCB's). Unfortunately, very little is known of these aspects in sea turtles, although PCB's have been found in the eggs of green turtles nesting at Ascension Island (Thompson et al. 1974), and Duguy (1983) reports that high levels of PCB's and DDE were found in tissue from three female turtles and one male leatherback turtle (see also Duguy et al. 1980).

Similar effects could be envisioned for turtles that ingest hard 'c fragments, styrofoam, synthetic line, and other plastic derivatives that make up 31.2% of the debris types shown in Table 4. An additional adverse factor may result from plastic objects grinding upon each other during muscular contractions in the digestive process. Such abrasive action could cause pinocytotic absorption of microscopic particles of plastic in the intestine, as has been suggested for albatrosses by Pettit et al. (1981). Furthermore, there would be a reduced ability to maneuver and dive away from predators when buoyant pieces of plastic and styrofoam are present in the gut. Buoyancy of this sort was clearly evident in Case I-Ei-11.

Another potentially serious aspect of the debris ingestion problem, but one that may prove easier to assess and alleviate, is the consumption of fishery by-catch by loggerheads. As suggested in Case I-Cc-6 by Shoop and Ruckdeschel (1982), the unwanted catch dumped from shrimp trawlers could be creating artifically high concentrations of foraging turtles. The turtles attracted would then be more susceptible to accidental capture and drowning from the intensive shrimp fishery. Increasing numbers of dead loggerheads washing ashore in the southeastern United States suggest that attraction to by-catch may indeed be a contributing factor.

Factors Causing Debris Ingestion

Several plausible explanations can be offered as to why sea turtles eat various debris. First, the object may resemble an authenic food item in size, shape, and even movement as it drifts at the surface or through the water column. Its color, translucence, and reflection may also be stimuli that induce a feeding response. In considering these factors, Hartog (1980) raised the interesting question as to why pieces of litter, particularly plastic objects, are not rejected by a turtle once "seized and tasted." A logical answer might be that marine organisms commonly encrusting or residing on debris may emanate an acceptable natural smell that masks the artificial nature of the object. Drift plastic is often covered with growth and, with increased ocean dumping, is considered to be an expanding pelagic niche for marine invertebrates (Winston 1982). In some cases, a luxuriant growth of marine life may be the principal sensory cue to initiate feeding by turtles. In Case I-Cm-7, a piece of synthetic net taken from the stomach of a green turtle had numerous fish eggs cemented to it. Although certain kinds of fish eggs are commonly attached to seaweed, floating debris like nets and other objects are also suitable habitat. Fritts (1981) presented information indicating that clumps of fish eggs may be an important nutritional source to sea turtles in the pelagic environment. In Case I-Cc-7, a piece of heavy monofilament fishing line pulled from the digestive tract of a loggerhead was found to have numerous encrusting organisms, the most abundant of which were mussels. It was surmised that the turtle ingested the line due to the presence of typical forage items for this species (L. Ogren pers. commun.). Gooseneck barnacles have been found in the stomachs of juvenile green turtles in Hawaii and elsewhere. These same barnacles have also been seen growing on small tar balls that have washed ashore in the Northwestern Hawaiian Islands. In the Atlantic, similar lumps of tar have been sighted at sea covered with barnacles, other crustaceans, and algae (Heyerdahl 1971). However, marine life of this sort may not always be necessary to attract turtles to eat floating tar. Owens (1983) mentioned preliminary studies suggesting that tar balls or soluble oil fractions by themselves might be inherently attractive to neonatal sea turtles (see also Hall et al. 1983).

The ingestion of plastics by turtles has recently generated some interest in Florida, where plastic seaweed mats may soon come into common use to control beach erosion (Van Dam 1984). Concern has also been expressed about fish aggregating devices made of vinyl screen which are anchored offshore 18 m (60 ft) beneath the surface. Foraging turtles, especially loggerheads, might bite into the vinyl while trying to eat encrusting organisms, or they may mistake the entire 1.8-m (6-ft) long parasol for a giant jellyfish (Benet 1984; R. Witham pers. commun.).

Under conditions of extreme hunger, turtles may be motivated to feed on debris that they would not otherwise eat. For example, at certain breeding sites there is a scarcity of forage to help sustain females through the 1- to 3-month nesting season. Ingestion of plastics, cloth, and other refuse by green turtles and hawksbills has been recorded in internesting habitats off Costa Rica and Ascension Island (see Case I-Cm-2, I-Cm-3, I-Ei-1, and I-Ei-2).

Another way in which sea turtles might ingest debris is through a secondary route, where the turtles' prey items have themselves eaten litter. There are no cases known at present to support such a mechanism; nevertheless, the increasing volume of minute plastic particles dispersed over the seas makes it a distinct possibility. For example, plastics and vegetables believed to have been dumped from fishing boats have been found in the stomachs of squid in the North Pacific (Araya 1983).

Impacts of Debris Entanglement

The adverse effects of debris entanglement on sea turtles are far more direct and obvious than more subtle negative impacts resulting from ingestion. As shown in Table 2, when turtles become entangled most of them are unable to function normally in feeding, diving, surfacing to breathe, and other basic behaviors. Constricting line and netting can inflict lesions and reduce blood supply to limbs, causing necrosis. Escape from predators is made more difficult, if not impossible. In addition, dense marine growth on entangling debris can weigh down a turtle, making it less likely to survive (see Case E-Dc-7). With the widespread use of synthetic line and net over the past few decades, there is little chance for entangling debris to rot away, or for a turtle to break loose on its own. Unfortunately for sea turtles, fishing gear of even greater durability (hence persistence) is now being advertised for sale (Anonymous 1983a).

Factors Causing Debris Entanglement

It is easy to understand how turtles can become entangled and drown in nearly invisible gear like monofilament netting. If the material is difficult to see underwater, a turtle may simply swim into it and become hopelessly tangled. Mortality from this cause has been reported from the intensive use and loss of large monofilament drift nets on the high seas northwest of Hawaii (Case E-Dc-3; Neuweiler 1982). Entanglement in other kinds of debris besides monofilament netting is more difficult to comprehend, since most are readily visible. Sea turtles, especially leatherbacks and green turtles, have a distinct propensity for entangling their front flippers and heads in rope. It is unknown exactly how these bizarre entanglements take place. Lazell (1976) describes a possible entanglement scenario for a leatherback trying to "eat" a buoy tied off with a rope.

Scraps of trawl net at sea seem to act like magnets to sea turtles. A likely explanation for this behavior is that floating masses of net offer the same advantages as sargassum mats or drift lines, where shelter and concentrated food can be obtained.

Once residency is established around a piece of net, the chances for a turtle becoming entangled may be quite high as it swims over and through the netting seeking food. In Hawaii, floating scraps of trawl net (often called "cargo" net) are viewed by fishermen as an asset due to their fish aggregating capabilities. Olive ridleys have been rescued alive from these nets by fishermen trolling around them (Case E-Lo-2, E-Lo-4, and E-Lo-5), even though this species does not normally occur in the nearshore waters of Hawaii. It is unknown if the surrounding high seas are normal habitat, or if the turtles became entangled at a distant site and passively drifted here.

Many kinds of drifting debris in addition to netting are known to aggregate marine life under and around them (Gooding and Magnuson 1967; Tsukagoe 1981). Sea turtles themselves can even act as natural aggregating objects. In Hawaii, trollers have caught several game fish at once lingering beneath a healthy immature turtle floating at the surface (Balazs 1981). Possibly the schooling behavior sometimes observed at sea for olive ridleys and other species has the benefit of attracting sources of food that can then be directly exploited by the turtles. Shipwrecked survivors adrift in a rubber raft north of the Galapagos Islands often had turtles (probably olive ridleys) around them in association with other marine life (Bailey and Bailey 1974). The turtles would rub against the bottom of the raft and, as might be expected, sometimes become entangled in ropes securing a sea anchor (Case E-Lo-1).

RECOMMENDATIONS

Short of severely curtailing the ocean dumping of all plastics and other material identified in this paper, there is probably not much that can be done to lessen the adverse effects of debris on sea turtles. The ubiquitous nature of the material and the mostly concealed oceanic life of many turtles, especially in their early development stages, present a difficult setting in which to work. There are, however, some immediate activities that could be undertaken to better understand the nature of the impacts. Of course the recognition that a problem exists, as has been facilitated through this debris workshop, is in itself an important first step.

It is recommended that the following actions be carried out.

1. There should be greater efforts worldwide to record stranded turtles and conduct necropsies aimed at documenting debris ingestion and entanglement.

2. Studies should be conducted that involve the controlled feeding of plastics and other debris to turtles in captivity to gain definite information on intestinal obstruction, absorption of plasticizers, and feeding behavior.

3. Field studies aimed at elucidating the pelagic life of sea turtles along drift lines in the Pacific should be undertaken north of the Hawaiian Islands.

4. A more thorough assessment should be made of sea turtle interactions with jettisoned by-catch from shrimp trawlers and other fisheries.

ACKNOWLEDGMENTS

I would like to acknowledge and express gratitude to the following persons for their valuable assistance in supplying information used in this paper: C. Afelin, L. Aguiar, C. Ahlo, A. Amos, J. Andre, K. Bjorndal, R. Bourke, P. Burnett, A. Carr, S. Dean, C. K. Dodd, D. Eckert, L. Ehrhart, N. Frazer, T. Fritts, S. Henderson, H. Hirth, G. Hughes, S. Kaiser, C. Limpus, C. Luginbuhl, E. Merrill, A. Meylan, K. McCoy, J. Musick, J. Naughton, L. Ogren, D. Owens, R. Prescott, P. Pritchard, W. Puleloa, J. Richardson, J. P. Ross, C. Ruckdeschel, J. Rutka, C. R. Shoop, K. Spinney, I. Uchida, T. Wibbels, J. Wilcox, and R. Witham.

Helpful comments on drafts of this paper were contributed by L. Ogren, A. Meylan, and N. Frazer.

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SOME CONSEQUENCES OF LOST FISHING GEAR

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ABSTRACT

Directed studies and incidental observations of derelict crab pots, longline gear, and sunken gill nets show some long-term damage to living marine animals. More than 30,000 crab pots have been lost in the western Gulf of Alaska since 1960. About 20% of legal size and 8% of sublegal king crab in these pots at the time of loss, fail to escape. The king crab which escape pots after a 10-day or more confinement, reenter the fishery at a very low rate, suggesting that relatively short-term confinement contributes to high mortality. Crab which die in a pot tend to repel other crab. Bright, bare hooks on halibut longline gear occasionally take fish, but plated hooks quickly rust or snag on sea floor objects. Although the nylon ground lines and gangions remain intact for several years, the hooks quickly cease to function. Three salmon gill net segments lost by Washington State fishermen have been observed for several years. The deployed segments ranged from 5.5 to 18.3 m (18 to 60 ft) below the surface. Each continued to fish for more than 2 years, taking a variety of fish, invertebrates, and seabirds. Underwater studies of the sunken gill net fishery for Pacific cod, <u>Gadus macrocephalus</u>, showed that only about 14% of the entangled cod escape before the net was retrieved. Consequently, most cod gilled, or otherwise tangled in sunken gill nets lost by fishermen remain until they die. Because set net fisheries are often concentrated on rough sea floor areas and among sunken man-made objects, significant loss of nets do occur. Some fishing gears are modified to quickly reduce their fishing capacity when lost.

INTRODUCTION

One hazard of the commercial fishing industry is the loss of fishing gear to a variety of causes. For some fisheries such as demersal longline and purse seine, the consequences of the gear components remaining in the sea may be slight. On the other hand, substantial injury or mortality to a wide variety of marine creatures occurs when traps (pots), gill nets, and other gear constructed of netting are lost.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

A number of experiments were conducted and field observations made by the author in cooperation with the Washington State Department of Fisheries, Alaska Department of Fish and Game, and the International Pacific Halibut Commission since 1974 to assess the potential loss of marine animals in derelict (ghost) gear.

DERELICT CRAB POTS

Hundreds of pots that are used in Dungeness crab, _Cancer magister_, fisheries are lost each year in coastal waters from Alaska southward to central California. Also, pots set in exposed shallow waters are often buried in sand during storms and unless crabs promptly escape from these pots, they will be killed from long confinement or during the sanding-in process (Tegelberg 1974).

Experiments were conducted using conventional, commercial-style crab pots to learn whether Dungeness crabs could escape from unbaited pots (High 1976). Legal (17.1 mm (6-3/4 in.) across the carapace) and sublegal crabs were placed in pots with functional triggers and escape rings. After 12 days, 55 and 23%, respectively, remained. Seventeen percent of the confined crabs died. Dungeness crabs were also placed in pots having functioning triggers across the tunnel as in the above experiment but with the normal 10.8 mm (4-1/4 in.) diameter escape ring sealed. After 74 days, 33% sublegal and 79% legal size crabs remained in the pots with 8 and 25% mortalities. It is likely that triggered pots which contain either sublegal or commercial size crabs at the time of the pots' loss will retain many until their death.

Similar experiments were conducted for king crab, _Paralithodes camtschatica_, because fishermen in Alaskan waters report losing about 10% of their pots per season as a result of various mishaps. With a fishery extending for over 24 years and considering the number of vessel licenses issued each year, more than 30,000 derelict pots could remain on the fishing grounds in operating condition (High and Worlund 1979). Interviews with fishermen revealed common causes of pot loss included: 1) buoyline breakage from chafing or entanglement in vessel propellers; 2) buoy puncture by sea lions; 3) pots carried into deeper water when tangled in gear such as trawls, longline, or other pots; and, 4) buoyline entanglements during setting, so that the line is shortened and buoys are carried under the surface.

King crab mortality from confinement in derelict pots occurred among those crabs in the pot at the time of its loss and crabs which, subsequently, enter because of 1) some form of bait, 2) the attraction of confined crabs, or 3) shelter offered by the pot (Fig. 1). However, entry of king crabs into a derelict pot is a nonproblem if the crabs can readily escape without injury. Experiments demonstrated that about 80% of legal size (about 145 mm carapace length) king crabs and 92% of sublegal king crabs would eventually escape. Interpreted conversely, 20 and 8%, respectively, would not escape. In addition, from tagging experiments, we learned that king crabs confined in a simulated derelict pot more than 10 days before release resulted in reduced recovery. Undoubtedly, extended confinement contributes to increased mortality.

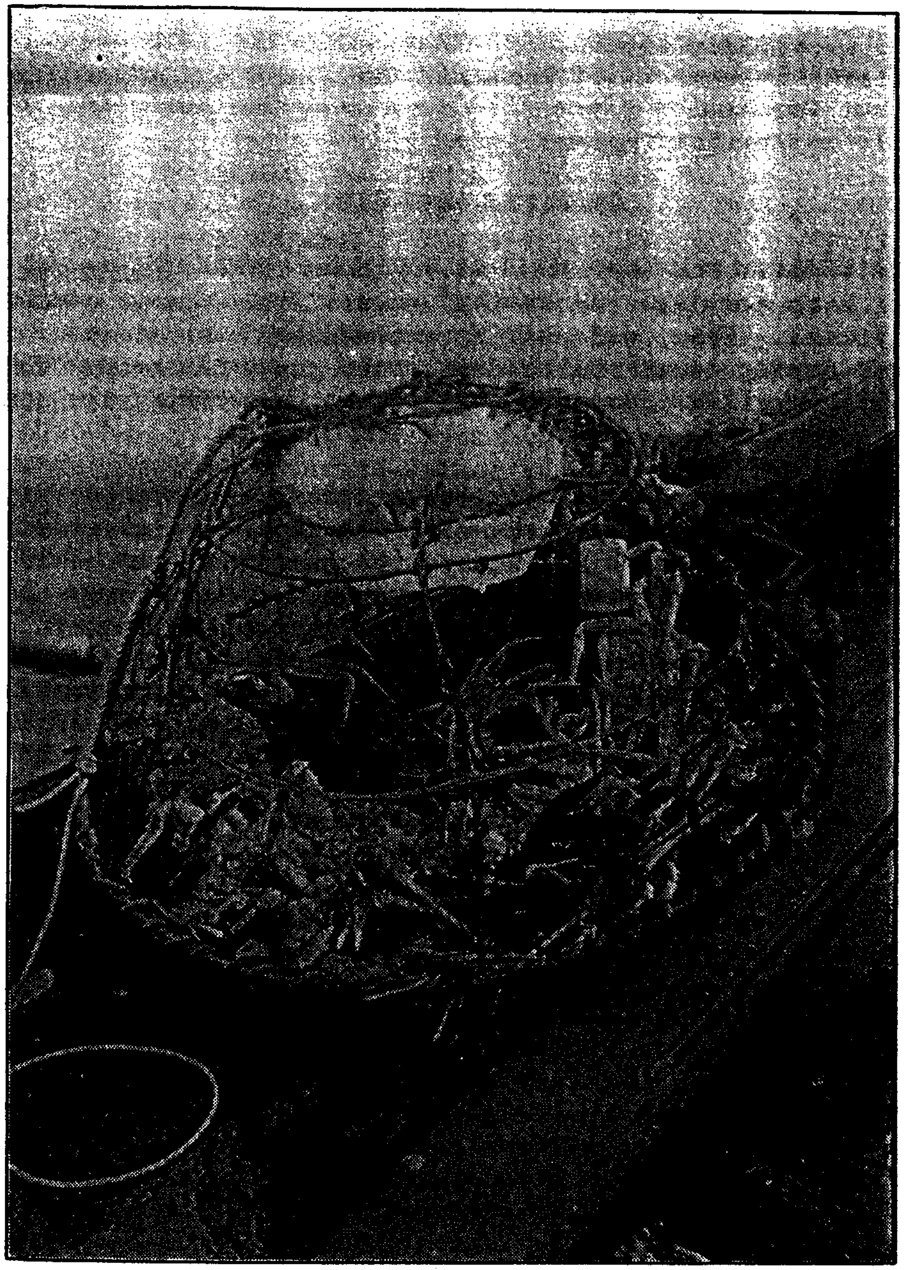

Figure 1.--This abandoned Japanese-type snow crab pot, recovered 3 months after close of the commercial fishing season, contained 12 king crab and 14 snow crab. One of each species was dead.

Pots baited with plastic jars containing Pacific herring, Clupea harengus pallasi, pieces attracted large numbers of king crabs at a decreasing rate up to 7 days, but did not cause the crabs to remain in the pot longer than in an unbaited pot. Some bait remained for the 7 days but decomposed quickly after 3 days. Dead crabs in pots did not attract king crabs to the pots.

Some fish species such as Pacific cod, Gadus macrocephalus, and Pacific halibut, Hippoglossus stenolepis, at times enter king crab pots in relatively large numbers. Fishermen reported that under some conditions, halibut were present in up to 9% of their commercial pot lifts, and up to 6% of our test fished pots contained halibut. When these species die in a derelict pot, the pot becomes rebaited for a short time. Although our studies of Dungeness crab and king crab pots did not establish the number of crabs which enter a pot following its loss, it is clear that large numbers of those crabs present at the time of the pot's loss and which subsequently enter while the pot remains intact are killed. Occasional derelict pot recoveries confirm that crabs continue to enter them. The problem of derelict pots, then, lies with the frequency with which crabs enter lost pots, the number of fishable derelict pots, and the mortality of crabs entering them. Estimates of the latter two parameters are now established.

GILL NETS

Gill nets deployed at the surface and near bottom have clearly demonstrated their effectiveness in many parts of the world. Because they are relatively cheap, easy to repair, and capable of fishing without constant care and attention of the fisherman, gill nets are often placed in loss-prone areas. For example, United Kingdom fishermen intentionally set gill nets across sunken shipwrecks because of the known fish aggregations. But gill nets can continue to fish for long periods after loss, even when only partially intact. Therefore, as derelicts, the nets create a potential for major loss to target and incidental species and also create concerns for vessels, people, and equipment.

Experiments were conducted to determine the escape of Pacific cod from sunken gill nets and the characteristics of the gear while fishing or after its loss. Only about 14% of cod observed tangled in commercial gill nets escaped prior to their retrieval.

Nets designed to fish from the sea floor 2.4-3.6 m (8-12 ft) up into the water column did so only during slack water periods. Even low, tidal generated currents caused the gill net to lie flat, thereby increasing the likelihood of serious snagging and entrapment of bottom species such as crabs and flounders.

Sunken gill nets fished in Alaska waters were required to be deployed at least 45 cm (18 in.) above the bottom to allow passage of crabs. Unfortunately, during several hours of each tidal cycle, these nets lay completely or in part across the sea floor, which defeated the objective of sparing the crabs.

Several large pieces of derelict salmon gill nets have been discovered in the course of other studies in Puget Sound, Washington. Each net, apparently abandoned, had become snagged at a depth of 24.4 m (80 ft) or less on some submerged object. For the most part, the netting pieces were left as found to observe the consequences of their presence. At irregular intervals, over a period of up to 6 years (at the time of this report), the nets were assessed for condition and contents.

Because of the relatively shallow depths of most of the nets, heavy algal growth developed within a year or less on the netting, and the catch of fish and diving birds decreased somewhat as algae density increased. Nonetheless, these animals continued to be caught for more than 3 years (High 1981). Crabs on the other hand, continued to become entangled after 6 years (Fig. 2).

Figure 2.--A red rock crab, Cancer productus and kelp crab, Pugettia producta, are shown entangled in an abandoned piece of salmon gill net.

Tidal currents, with time, caused some of the netting to roll into a pile or sausage-shaped bundle on the bottom. Fish and birds are less often entangled by rolled netting than are crabs.

The synthetic net material remains adequately strong to hold living animals 6 years after its loss, although no objective test of thread tensile strength has been made.

Like the marine animals of which we most often speak, man himself has become the victim of his own synthetic technology. Divers have occasionally, over many years, suffered the usually frightening experience of temporary entanglement in monofilament fishing lines. However, more recently, near tragic encounters have occurred with active and derelict set nets. Diver magazine of London, England graphically describes several near fatal entanglements by recreational divers (Anonymous 1984). Vessel wrecks are the common attraction for the diver and commercial fishermen. As stated elsewhere in this report, fishermen of the United Kingdom intentionally set nets across wrecks, accepting a high loss of gear to harvest the abundant fish attracted to the artifical reef. Likewise, divers seek out the same wrecks as highly desirable work and recreational areas. Members of my own diving team underwent extensive training and modified their dive gear to better prepare them to work near active and derelict nets. Nonetheless, entanglement was common. Recreational divers are ill prepared to deal with the stress and constraints imposed by netting.

Diver knives are poorly designed and maintained to cut loose nettings. The knife itself often becomes the initial snag site and cannot be removed from its sheath. All divers who have a high likelihood of encountering line or netting underwater should carry a second, small, very sharp knife near their wrist or upper arm, specifically to help cut such entanglements.

LONGLINE

Demersal halibut longline gear, composed of individual hooks attached by leaders (gangions) at intervals along a groundline, fishes effectively only while the hooks are baited. One study shows that <25% of herring, Clupea harengus pallasi, bait remained after 2 h of fishing, whereas octopus, Octopus dofleini, a more durable bait, remained on the hook for several hours (High 1980).

Occasionally, halibut was observed to attack a bare, bright hook (High in press). However, hooks in the water tarnish within a few days and it is not likely they continue to attract fish even though many thousands of hooks on longlines are lost each year (Fig 3).

SUMMARY

It is clear that some derelict fishing gear contributes to a loss of marine animals for as long as the gear remains intact. Studies show that nets can still entangle fish after more than 6 years underwater. Crab pots, because of their extremely rugged construction, may fish for even longer periods. Some small and commercial sized crabs confined in derelict pots fail to escape or are possibly injured in some way by long confinement which reduces their survivability. Halibut longline gear is lost in quantity but the hooks have their bait removed within hours by predators and only occasionally do fish take the bare hook.

Figure 3.--An underwater view of halibut longline entangled on a barnacle encrusted boulder.

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UNDERWATER SURVEY OF SIMULATED LOST DEMERSAL AND LOST COMMERCIAL GILL NETS OFF NEW ENGLAND

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ABSTRACT

The increase in commercial and recreational fishing pressure in the New England ground fishery over the last decade has intensified the problems of gear conflict and preemption of prime fishing bottom by one particular gear. A major issue has been the demersal gill net, especially when it may be lost and ghost fishing. The Massachusetts Division of Marine Fisheries initiated two investigations on simulated ghost gill nets. The purpose of this effort was to establish methods to evaluate certain characteristics of a net set over an extended period of time, to evaluate net profile, and to monitor the catch rate and fate in the nets. One net was set in May 1982 and monitored periodically through June 1982. The catch, primarily spiny dogfish, Squalus acanthias, usually tangled in the net and depressed the height of the net. The second net was set mid-February 1983. Eleven dives were made on the net before its retrieval late April 1983. This commercial net had marked panels that assisted detailed assessment of the net profile and fate of fish caught in the net. The predominant species caught was Atlantic cod, Gadus morhua. Also caught were cunner, Tautogolabrus adspersus, sea raven, Hemitripterus americanus, and tautog, Tautoga onitis.

In July 1984, the National Marine Fisheries Service and the Massachusetts Division of Marine Fisheries initiated a more thorough study of ghost gill nets using the submersible Johnson Sea-Link II and the RV Johnson. Part of this 3-year study was to survey prime fishing sites for the frequency of lost nets and determine the impact of these nets on the fishery resource. ʻeen submersible dives surveyed over 40.5 ha of bottom in the of Maine. We saw nine ghost gill nets, six balled up and off the bottom to heights up to 3.6 m; three stretched out ally but with reduced float line heights. Extensive

Yoshida (editors), Proceedings of the Workshop on the Fate and Impact ember 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. 4. 1985.

video and still shots documented the nets and the catch in the nets. The catch, live or decaying, included Atlantic cod; Atlantic wolffish, Anarhichas lupus; spiny dogfish; winter flounder, Pseudopleuronectes americanus; American lobster, Homarus americanus; and crabs, Cancer spp. The ghost gill nets seen on these dives may be over 3 years old. We estimated the age of the nets observed through the marine invertebrates attached to the nets and by comparing eight of the nets to one net known to have been lost 3 years ago. Also discussed are the probable reason of the loss of these nets, the impact of these nets to the fishery resources, and future research to reduce any impacts.

INTRODUCTION

The increase in commercial and recreational fishing pressure in the New England ground fishery over the last decade has intensified the problems of gear conflict and preemption of prime fishing bottom. A major issue in this controversy is the use of the demersal gill net.

Gill nets are a fixed type of fishing gear marked by floats at each end of the net. In the Gulf of Maine demersal gill nets, each being about 91 m (50 fathoms) long, are usually set in strings of 10 to 12, (one string) totaling 914 to 1,097 m (500 to 600 fathoms). A single vessel sets between five to six strings, thus occupying a considerable expanse of ocean.

Mobile gear fishermen and those utilizing fixed gear are often in conflict when they try to use the same sea bottom. Due to recent advances in trawl gear allowing draggers access to rougher bottom terrain, gill-netters have been forced to set their nets in more concentrated areas. The areas are those often preferred by recreational fishermen in private vessels as well as those on charter and party boats. Many recreational fishermen fish by drift fishing and jigging off the bottom, seeking the same species (cod, haddock, and pollock) as the gill-netters. The conflict is obvious: The drift fishing recreational fishermen use the same areas as the gill-netters and become fouled in the gill nets.

Ghost or derelict gill nets are nets lost due to storms or entanglement with mobile gear. Some evidence exists that ghost gill nets continue to catch fish and foul mobile gear. The bodies of gill nets are typically constructed of monofilament netting line, hence there is a question as to the longevity of ghost gill nets and their possible effects on the fish stocks and interference with other gear types.

Bottom trawlers (draggers) have retrieved lost gill nets in Massachusetts waters (Capt. Dan Arnold, Capt. Frank Mirarchi, pers. commun. 1981). Fish entangled in the nets were found in various stages of decay. Party boats have also reported hooking ghost gill nets and retrieving pieces of net containing entangled and dying fish, lobsters, and crabs.

Canadian biologists have researched the question concerning the continued fishing of ghost gill nets (Way 1977). The conclusions, although still controversial to some, are that generally the lost nets continue to fish at uncertain rates for undetermined periods of time. The damage intensity and longevity appear related to finfish and crustacean species and abundance, the net characteristics, bottom type, current, and surge. Research into the problem has been accomplished using retrieval techniques. Little work has been reported on in situ techniques using underwater observation and evaluation. Quantitative data dealing with this problem are, therefore, very limited.

The Massachusetts Division of Marine Fisheries (MDMF) initiated an investigation by setting two demersal gill nets and leaving them on the sea bottom to simulate ghost gill nets. The first was set in May 1982 and the second in February 1983. The purpose of this effort was to perfect an in situ research method utilizing scuba to evaluate change in net profile over time, and monitor the catch rate and fate of the nets. The results are reported herein.

In August 1983, personnel from the National Marine Fisheries Service (NMFS) and the MDMF conducted a 7-day cruise with assistance from the recreational and commercial fishing industries to assess the usefulness of various surface operated gear in detecting ghost gill nets. Seven sites of recent conflict between the above mentioned fishing interests were surveyed using high resolution sonars, grappling gear, and underwater television. The results demonstrated that actively fished nets can be easily detected through a variety of acoustic methods when the bottom is not very irregular. No ghost nets were seen or retrieved during this survey.

In 1984, with the question of the effects of ghost gill nets unresolved, NMFS and MDMF undertook a more thorough study using the submersible Johnson Sea-Link II and the support vessel RV Johnston, from the Harbor Branch Foundation, Ft. Pierce, Florida. The first phase of a 3-year study was 1) to study prime fishing sites for the frequency of ghost gill nets and to begin to determine impact of these nets on the fishery resource and 2) to work with gill-netters to observe fish behavior in and around active commercial gill nets.

METHODS AND MATERIALS

In May 1982, we initiated the in situ gill net investigation by setting a 91.4 m (300 ft), 14 cm (5.5 in.) mesh monofilament demersal net in 18.3 m (60 ft) of water in Cape Cod Bay. The net, similar to those used by most gill-netters in the area, was marked with numbered plastic tags on the float and leadlines every 9.1 m (30 ft) so that divers could accurately survey the net profile and catch of each 9.1-m panel. Four scuba dives were made on this net. Divers utilized clipboards with waterproof paper to record visual observations. A diagram of the net, divided into 10 numbered 9.1-m panels, was illustrated on the waterproof paper, allowing divers to record the vertical profile of the net, where and how each species was caught, and the life state of each fish.

Fish are caught in gill nets three ways. The most common is by being "gilled," i.e., a fish swims into the "invisible" monofilament net where the head fits, but the girth of the fish prevents complete passage through the mesh. The fish cannot back out of the net because the mesh catches on the open operculum. A fish may also become wedged in a mesh, i.e., it swims into the mesh until it is held tightly around the body. The third method of net capture can be referred to as "tangling" or "entanglement;" the fish does not penetrate a mesh but is snared either by its teeth, maxillaries, fins, or other projections.

A second gill net of similar construction was deployed on 14 February 1983, for a period of 74 days. The net was set at the same depth, perpendicular to, and 0.5 nmi from shore. The only difference in the net was the marked panel interval, which was reduced from 9.1 to 4.6 m (30 to 15 ft). Scuba dives were scheduled once a week. Divers recorded the same information as in the previous experiment.

In June 1984, the submersible Johnson Sea-Link spent 9 days in New England waters diving in areas recognized as active commercial gillnetting sites (Fig. 1). The submersible dive sites were selected through three methods:

1) by a survey of gill net gear distribution from the NOAA RV Gloria Michelle in April 1984 when gillnetting was most active,

2) through current information acquired from mobile and stationary gear fishermen,

3) from groundfish party boat operators who operate daily in the same fishing areas.

We chose specific submarine dive transects after a review of the bottom topography and a limited amount of additional bottom profiling of the sites. The Johnson Sea-Link carried a pilot and scientist forward in the sphere, and a scientist and crewmember aft in the lockout chamber. During each dive, the pilot would normally follow a defined transect unless a net was encountered; in this case, the net was fully surveyed and then the transect continued. Each scientist had an audio tape recorder and a Benthos[1] 35-mm still camera mounted externally on the submersible to record his observations. The team in the forward sphere also had an externally mounted video camera that they were able to manually pan, tilt, and zoom. The Johnson Sea-Link was tracked via sonar from the RV Johnson. Location fixes of the launch, net locations, and recovery were recorded using the loran C navigational system.

RESULTS AND DISCUSSION

In Situ Scuba Observations

Diving on the first net (set in May 1982 and lost mid-July 1982) was instrumental in perfecting in situ surveying procedures utilizing scuba. The predominant species caught was the spiny dogfish, *Squalus acanthias*. On the first dive, 18 h following the set, spiny dogfish, struggling to free themselves, effectively caused tangling and overlapping of float and leadlines throughout more than half the net. In 42 h the vertical profile

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[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

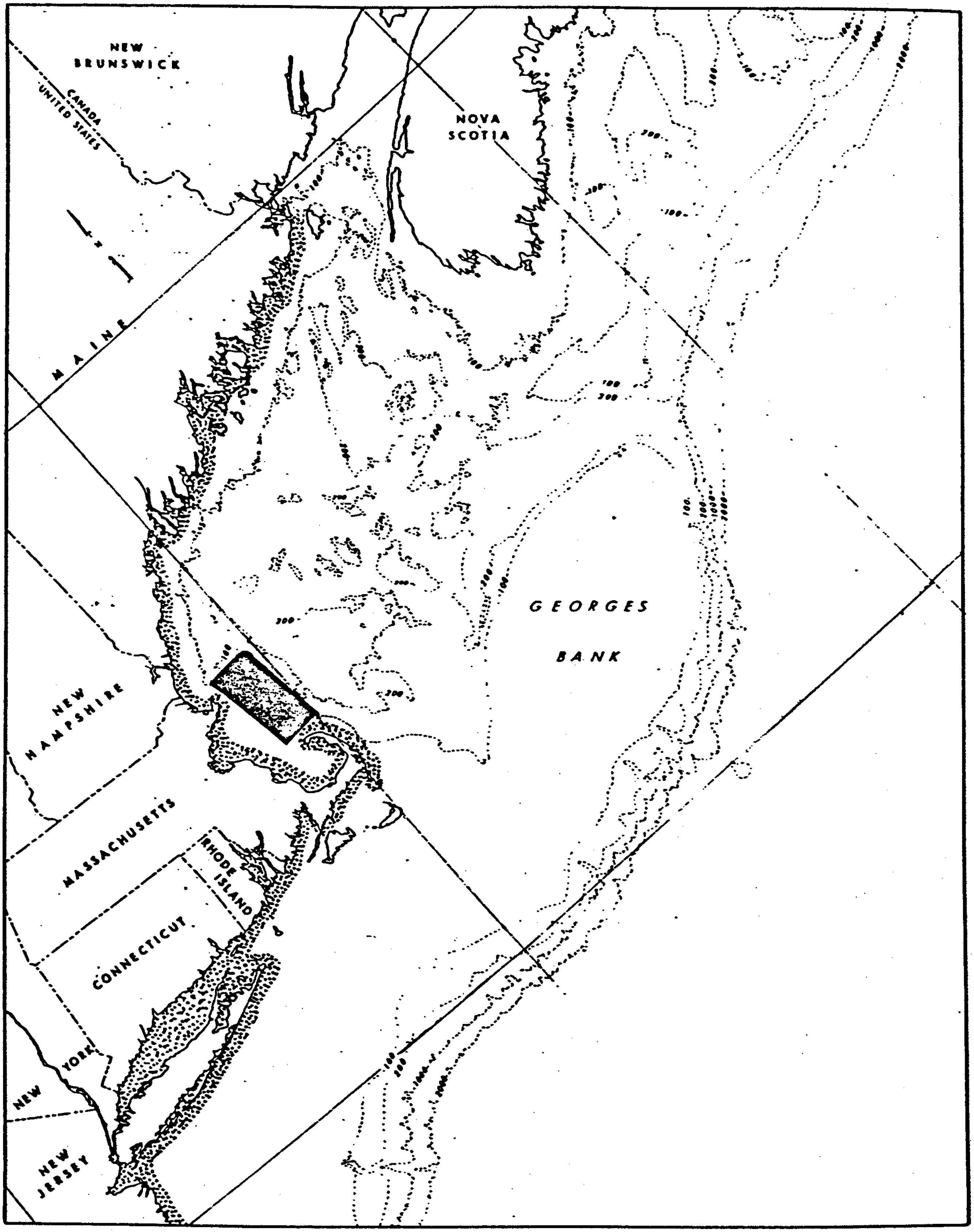

Figure 1.--New England-Gulf of Maine study area.

of 50% of the net was depressed to <0.6 m (<2 ft) off the bottom. A month later the entire net, twisted, and tangled, was similarly reduced to <0.6 m. The sketched diagram of the net used by divers assisted the plotting of profile and catch. However, the low visibility, <4.6 m (<15 ft), made identification of specific net panels difficult using float and leadline tags spaced 9.1 m (30 ft) apart. Further, it was discovered that diving surveys should be weekly or more frequent, to better understand the fate of the catch.

The second net was set for a period of 74 days between 14 February and 28 April 1983. The northeast end was fixed to a shipwreck and the southwest end anchored with cement blocks. Currents at this site were usually <1 knot. The net maintained its 1.8-m vertical profile for 10 days. Within 30 days, the net, after a northeast gale, had swung 90° from its initial set, from southwest to southeast. Most of the panels were still nearly 1.8 m in height with the exception of sections that came into contact with various debris such as lost lobster pots (Table 1). In 50 days, 60% of the net had a height not exceeding 1.2 m. By the 73d day 85% of the net was twisted with a mean height <1.2 m (4 ft). The loss of vertical profile appeared related to storm surge and fouling on fixed bottom debris.

Table 1.--Net profile (%) of gill net set, February-April 1983.

Panel mean height (in feet)	February	March				April		
	22	1	14	21	29	5	12	28
6	100	100	70	20	10	25	--	--
>4	--	--	30	50	50	40	45	15
2-4	--	--	--	30	25	40	35	30
<2	--	--	--	--	--	--	5	45
Tangled or twisted	--	--	--	--	15	20	15	10

Various species of algae began to collect on the knots of the net within 8 days of the set. This fouling continued to increase over time, but did not clog the net nor did it appear to cause a major reduction in net height profile. Large blades of *Laminaria* and pieces of *Ulva* sp. were swept into the net, but collected mainly near its base.

Although this net was set in shallow water that was not commercially fished by gill nets and the algae that fouled the net were different from any that would be usually found in commercially set areas, we believe that the fouling condition exaggerated what would normally happen in commercial areas and were interested to observe that the net did not collapse to the bottom because of this algal fouling.

The predominant finfish species caught were cod, *Gadus morhua*, and tautog, *Tautoga onitis* (Table 2). Most of the cod were caught between days

Table 2.--Catch (by species) in gill net set between February and April 1983.

	February			March				April				
	15	17	22	1	14	21	29	4	7	12	28	Total
Day	2	4	9	16	29	36	44	51	53	58	74	--
Species												
Gadus morhua	--	--	1	--	6	4	2	5	--	--	--	18
Urophycis tenuis	--	--	--	--	--	--	--	--	--	--	1	1
Pseudopleuronectes americanus	--	--	--	--	--	--	1	--	1	--	--	2
Scophthalmus aquosus	--	--	--	1	--	--	--	--	--	--	--	1
Tautoga onitis	--	--	--	--	--	--	--	--	--	1	13	14
Tautogolabrus adspersus	--	--	--	--	--	--	1	1	2	1	--	5
Hemitripterus americanus	--	--	--	--	--	--	--	--	2	--	--	2
Raja sp.	--	--	--	--	1	3	2	--	--	2	1	9
Cancer borealis	--	--	1	3	7	17	14	15+	16+	12+	12+	97+
Homarus americanus	--	--	--	--	--	1	--	--	--	--	--	1
Seawater temperature °C	1°		1°			4°					10°	

17 and 51 of the set. The catch of cod was probably higher during this period because of their coastal migration in early April. Tautog were caught near the end of the experiment, between days 54 and 74 when waters were warming up and they moved into the area for late spring-summer residency.

A similar commercial net was set next to the experimental net on 5 April for a 2-day period. The purpose was to compare the catch of the clean gill net with the "ghost" gill net during a time when cod were present in the area. No fish were caught in the freshly set net. One tautog, a cunner, Tautogolabrus adspersus, and two skate, Raja sp., were noted as new catch in the experimental net.

Submersible Observations

The submersible Johnson Sea-Link made 15 dives that averaged 2-1/2 h each. Twelve dives were made on Jeffreys Ledge and 3 on Stellwagen Bank (Fig. 2). Thirteen of the dives searched areas for ghost gill nets. Two dives, both on Stellwagen Bank, investigated active commercial gill nets. We surveyed over 40.5 ha (100 acres) of active gill net fishing areas and located 10 ghost gill nets. All of the ghost nets had bryozoans growing on the monofilament. The anemone, Metridium sp., and stalked ascidian, Boltenia sp., were also attached to some nets. Most of the ghost gill nets were located on ledges with rocks and boulders.

Four of the ghost gill nets were twisted into snarled bundles rising up to a maximum of 3.6 m (12 ft). These vertical configurations were 0.6 to 0.9 m (2 to 3 ft) and varied between 1.5 and 3.6 m (5 and 12 ft) high. The floats, usually encrusted with barnacles, kept the twisted mass buoyant while the leadline was caught in the rocky bottom. Two of the four nets

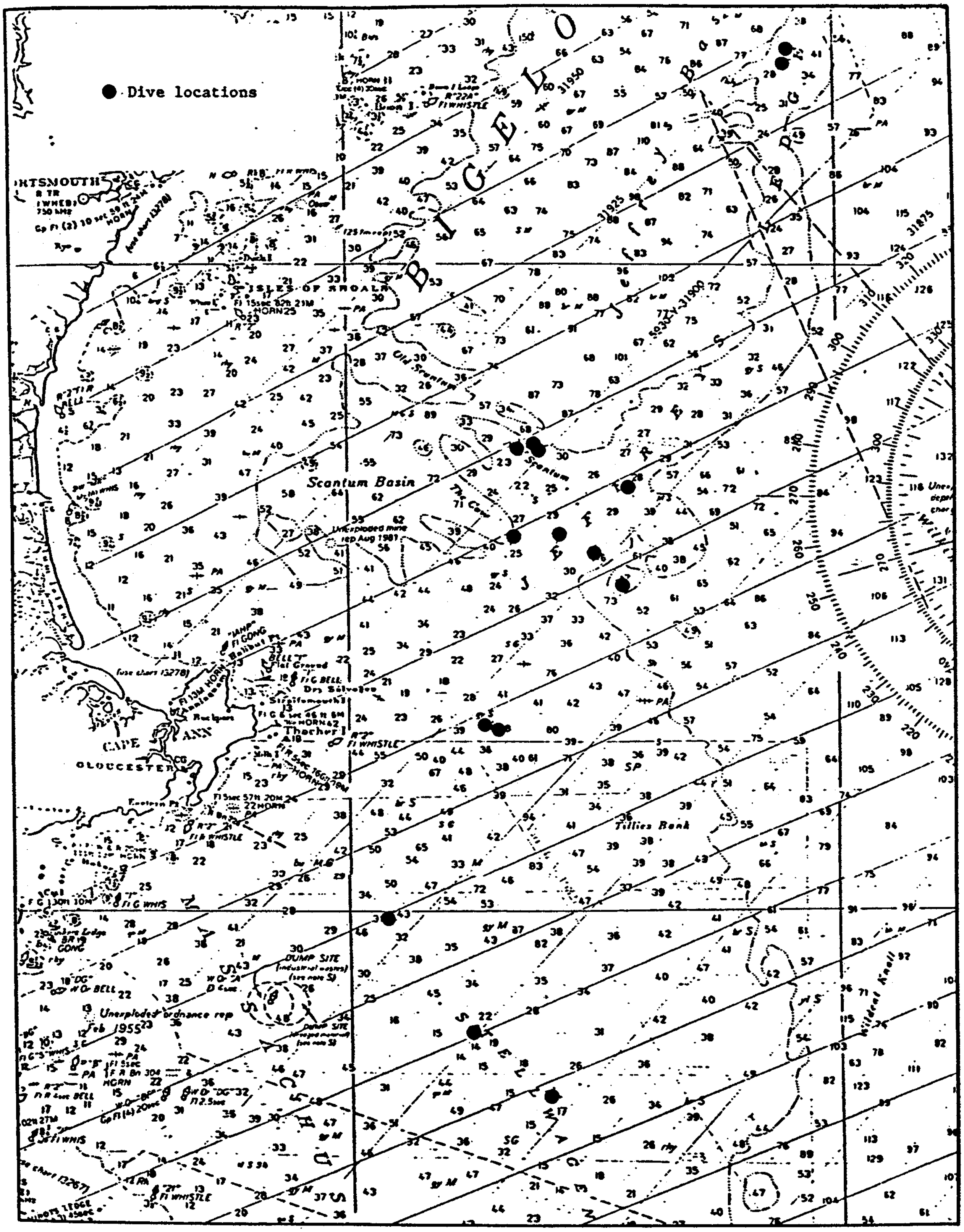

Figure 2.--Submersible dive transects.

had one and two dead dogfish, respectively, each tangled in the webbing. No other species were caught.

Two nets were actually short horizontal pieces <9.1 m, with a twisted, vertically rising mass on one or both ends. One of these net fragments, stretched horizontally for approximately 9.1 m, had a snarled mass on one end rising up 3 m (10 ft) off the bottom. The horizontal segment had several tears in the webbing and a twist between the float line and leadline. Its maximum float line height was 0.6 m off the bottom. One dogfish and three lobsters, *Homarus americanus*, were caught in this section. No fish were caught in the vertically twisted mass. The other net consisted of a 6.1-m (20-ft) horizontal piece between two vertically twisted bundles. The only fish caught were two dogfish in the stretched section. Although the end bundles had no fish, numerous starfish, *Solaster endeca* and *Asterias* sp., were clustered at the base of each. This suggests that these snarled masses, although barren of any catch during our observations, had snared fish that provided a source of food for the starfish.

Four ghost nets found were stretched horizontally along the bottom, varying in length from 61.0 to 228.6 m (200 to 750 ft) with a vertical profile usually reduced to <0.6 m (<2 ft). These nets caught the most fish, even though each net had a combination of float and leadline twists, large irregular holes in the webbing, and a reduced vertical profile. The predominant species caught was the dogfish. A typical example of the catch in any 91.4 m (300-ft) section of net was 12 dogfish, 1 wolffish, *Anarhichas lupus*, 1 sea raven, *Hemitripterus americanus*, and a lobster. All were tangled in the net. The dogfish, judging by their color and state of decomposition, were recently caught. A notochord near the leadline of the net was evidence of predation around its vent. Cancer crabs and starfish were in and near the net; some starfish were feeding on the caudal region of a dogfish. Pollock, *Pollachius virens*, and cunner swam through portions of the net.

All of the ghost nets appeared to have been underwater for 2 years or more. We determined this by the colonization of bryozoans on the monofilament and the presence and size of the anemones, stalked ascidians, and Halichondrina sponge on the float lines. We also knew the age of one net. Its condition enabled us to compare the growth and level of deterioration of that net to the other nets. This horizontal net, placed 3 years before our survey, went down with the gill net vessel during deployment of a string of nets. One submersible dive surveyed the vessel and the nets still attached to the vessel.

The nets that lay stretched horizontally had a mean vertical profile of 0.4 to 0.6 m (1-1/2 to 2 ft). This represented a vertical profile that was 25 to 33% of an active demersal net used in New England waters. The efficiency of these nets was further reduced by the growth of bryozoans on the monofilament which made the net more visible, and by the numerous holes in the net. We estimated the total linear distance of all reduced horizontal gill net sections observed in 1984 to be 548.6 m (1,800 ft).

We have no definitive explanation for the three different net configurations found. Discussions with gill-netters, trawler fishermen, and recreational fishermen led to several hypotheses: The horizontally stretched nets may have lost their buoy lines and therefore became lost; the vertically tangled nets may have become fouled on rocky bottom which prevented successful retrieval, or they may have been fouled by the mobile trawlers.

Limited observations were made on commercially set nets. The dives on active gill nets were intended to observe cod, which unfortunately were displaced by the influx of spiny dogfish. During surveys of three gill nets set for dogfish, we acquired interesting video documentation of the entanglement behavior of dogfish, winter flounder, *Pseudopleuronectes americanus*, skate, and cod. The second purpose of the initial survey was completed successfully: A survey of areas of high gillnetting activity was carried out and a determination made of relative ghost gill net abundance in these areas: 10 lost nets of varying length on 4.0 ha (10 acres) of bottom.

We believe it is premature to draw any firm management or economic impact conclusions on the effects of ghost gill nets on the fishery resources off New England from the information gained on this initial survey. The most abundant catch was dogfish which at present has minimal economic importance to the industry. Although gill-netters did report cod in the vicinity, cod were not observed as the primary catch in the ghost gill nets, nor were any substantial skeletal remains observed around the base of the nets.

During the second year of this program, our initiative will be threefold:

1) To look at active gill nets and ghost gill nets when cod are more abundant. The purpose is to observe another stage or window of activity of the nets and the impact on the cod resource.

2) To return to several of the ghost gill nets found in the summer survey of 1984 and record their status 1 year later.

3) To experiment initially with modifications to a demersal gill net to see if its continued fishing, when lost, can be reduced.

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THE PROBLEM OF FUR SEAL ENTANGLEMENT IN MARINE DEBRIS

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ABSTRACT

Many fur seals die by entanglement in fishing nets discarded or lost by fishing boats. This is reported to be a major cause of the present decrease in the number of fur seals and has been the subject of discussion by the North Pacific Fur Seal Commission.

A 3-year study started in 1983 placed particular emphasis on analyzing the actual reasons why fur seals become entangled and how they behave while entangled.

The main study items are as follows:

1. Collection of data concerning the actual condition of lost nets, the number of entangled fur seals, the feeding behavior of seals, etc., at sea.

2. Survey of the rookery islands to count fur seals entangled in marine debris, survival period of entangled fur seals, rate of fur seal escapement from entangling nets, effect of entanglement on the growth of fur seals, counting nets washed ashore, etc.

3. Experiments using fur seals raised in captivity to determine how fur seals (a) become entangled in fragments of nets, (b) escape from nets, (c) are injured by nets, and to determine how the weight of the net is related to the feeding behavior of the fur seals, etc.

The preliminary data collected in these surveys and experiments are reported in this article.

INTRODUCTION

The first report on the net entanglement problem of fur seals was submitted by the U.S. scientist to the Standing Scientific Committee of the 10th Annual Meeting of the North Pacific Fur Sea Commission. At that time,

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

the decision was made to proceed with the collection of research material to analyze the problem in more detail. At the 11th meeting, the American representative proposed a survey to carry out a detailed analysis of net entanglement, and a study to determine the origin of 50 samples of net fragments recovered in the Pribilof Islands was assigned to the Japanese team. Results of the determination on the origin of the samples was reported to the 12th annual meeting by Japanese scientists (Japan 1969). The report stated that except for one piece of rope used in crab gill net fisheries and two plastic bands, all samples were of trawler net fragments. It was estimated that most of the fragments, excluding a small portion, would be of Japanese origin. However, since nets made in Japan are exported in quantity, it was impossible to identify the country that was actually responsible.

In the subsequent 12 years up to the 24th annual meeting, a few reports on this problem had been submitted by the United States and the Soviet Union, and although the impact of marine debris on the fur seal population remains unclear, it was agreed that the problem was of major importance and that research efforts should be intensified. At the Standing Scientific Committee meeting of the 25th Annual Meeting of the North Pacific Fur Seal Commission, the United States reported that the fur seal population of the Pribilof Islands had been reduced by 5% due to net entanglement, and that the problem was causing a deterioration in fur seal population. In response, the Japanese stated that the base value was based on erroneous data and that a 5% rate could hardly be assumed. The United States also agreed that it was still too early to draw such a conclusion. In 1983 at the Standing Committee meeting of the 26th annual meeting, the United States reported a death rate of almost 10% due to net entanglement, and in the general meeting stressed that although the decline of the population in the Pribilof and Robben Islands could not be directly related to net entanglement, that it was a prime candidate, and should be promptly investigated by the member countries. In response, Japan and Canada replied that the death rate due to net entanglement had not changed over the last 10 years, and that the population decline was perhaps exaggerated. The Soviet Union was of the opinion that the fragments were simply part of the pollution of the oceans and did not recognize any increase in net-related deaths. Nevertheless, all member nations agreed to proceed with trying to find a solution to the problem.

Taking into account the above progress, the Japanese acknowledged that a scientific approach was critical and started the following 3-year survey running from 1982 to 1985.

METHODS

The investigative plan consisted of three sections: an oceanic survey, an investigation of the rookery islands, and an experimental investigation of seals under controlled conditions. The goal was to identify the actual extent of net entanglement, mechanism of the entanglement, and determine the behavior of entangled seals.

Oceanic Survey

In addition to the standard survey factors (fur seal distribution, migrations, mixing, age composition, feeding habits, habitat, reproductive rates, etc.), other factors such as the number of net fragments floating in the ocean, the number of fur seals entangled, and the feeding activities of entangled fur seals were also investigated.

Investigation on the Rookery Islands

Data were collected on the entanglement and escape rates of male fur seals, as well as the average period of their survival under entangled conditions. Also, the entanglement rate of female fur seals and the number of net fragments washed on shore and the growth of seals which had been entangled were also investigated.

Experimental Research

Under a contract with an aquarium, the Far Seas Fisheries Research Laboratory proceeded with research into the conditions under which fur seals become entangled in drifting net fragments, the possibility of escapement from it, the development of scars caused by net entanglements, and the relation of net fragment weight and feeding activities of entangled fur seals.

RESULTS

Oceanic Survey

A report on the estimated number of floating net fragments and entangled fur seals in the survey areas will be summarized and presented at the end of the 3-year research period in 1985. Therefore, this report will only present data obtained by the surveys from 1982 through 1984.

Survey by One Research Vessel, 1982

Survey area.--Okhotsk Sea near Robben Island.

Survey period.--3 July to 11 July 1982.

Purpose.--The survey was done to determine if rope and net fragments could be detected by visual search.

Results.--Seven floating trawler net fragments were discovered, and in three of them was entangled either a fur seal or harbor seal. One of the fur seals was already dead when discovered.

Survey by Two Research Vessels, 1983

Survey area.--Pacific coastal waters off northern Japan and Hokkaido.

Survey period.--1 November to 26 December 1983.

Results.--Three salmon gill net fragments, three squid gill net fragments, and four trawler net fragments were discovered. A fur seal was found entangled in one of the trawler net fragments.

Survey by Two Research Vessels, 1984

Survey area.--Pacific coastal waters off northern Japan and Hokkaido and the coastal waters off the Pribilof Islands in the Bering Sea.

Survey period.--18 January to 17 March 1984 and 3 July to 30 August 1984, respectively.

Results.--Four salmon gill net fragments, 1 plastic band, and 10 trawler net fragments were discovered. A fur seal was found entangled in one of the trawler net fragments.

Investigation on the Rookery Islands, 1983 and 1984

Two scientists from Japan were dispatched to St. Paul Island to conduct a joint survey with United States scientists to investigate net entanglements of fur seals on the rookery islands. The investigation covered the number of male fur seals entangled, identification of the entangling materials, scarring, escape rates, growth of seals after having been entangled, and types and weights of fragments found on the shores of the islands. The results of 1983 survey were reported in 1984 (Scordino et al. 1984).

The 68 samples of net fragments collected on St. Paul Island during the 1982 breeding season were sent to Japan for analysis in 1983, and the results were reported in 1984 (Yoshida et al. 1984).

About 1,500 samples of net fragments and plastic bands collected on the shores of the rookery islands during 1982-84 and recovered from fur seals during 1981-84 were sent to Japan for analysis. This material is currently being studied.

Experimental Research

In 1983 experimental research was conducted at the aquarium on the conditions under which seals became entangled, the possibility of escapement, the effects on feeding of entanglement, and the injuries and scars caused. The results have already been reported in "The 1983 report on the fur seal entanglement problem aquarium experimental research." This research is continuing. The results of the 1983 research is as follows:

Twenty-two fur seals were studied; 20 had been captured along the coast of Japan and kept in captivity for 2-4 years, and the other 2 were shipped from Robben Island while young and raised at the aquarium on artificial milk.

The net fragments utilized were eight pieces of polyethylene trawler net in total, with mesh sizes of 24 and 40 cm, and weights of 100 and 200 g, respectively. In addition, four polypropylene cargo bands 15.5 mm wide, and 16 cm in diameter, colored blue and yellow, respectively, were also used.

The total number of fur seals entangled in either net fragments or bands was 9 out of 22 (41%), with a total of 12 cases of entanglement observed.

The period until the seals became entangled ranged from 18 h to 34 days, and entanglement usually resulted when they charged forward at high speed without recognizing the floating objects. For the young seals, entanglement during play was also frequent.

Of the seals becoming entangled, 10 were observed to escape from the fragments, within a range of 2-5 days after becoming entangled. The two young seals were frequently entangled in and escaped from the fragments.

No effect on the behavior of the seals after their entanglement was observed.

Temporary drops in the amount of feeding by entangled seals were observed for periods of up to 10 days.

There was no apparent drop in seal weight during the time they were entangled, and some even gained weight.

There was almost no scarring due to entanglement, and even the seal that was entangled for the longest time only suffered a slight ruffle of fur.

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INCIDENTS OF MARINE MAMMAL ENCOUNTERS WITH DEBRIS AND ACTIVE FISHING GEAR

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INTRODUCTION

This paper summarizes the encounters of marine mammals with debris and active fishing gear that I have observed (with an emphasis on the Oregon coast) since 1968 or that have been reported to me with substantiating evidence by reliable sources. From 1968 to 1972, most of the observations were my own, during doctorate research, on the numbers of sea lions utilizing the Oregon coast throughout the year (Mate 1975). During this time, I was stationed at the Oregon Institute of Marine Biology in Charleston, Oregon and most of the observations were made within 100 km of that location. From 1973 through 1975, I was a less frequent observer along the coast and my attention was only drawn to incidents through personal contacts. Since 1976, I have been based at an active marine laboratory in Newport, Oregon and my observations have been supplemented by a network of collaborating Oregon agencies (Department of Fish and Wildlife, State police, highway department, and State parks), Federal authorities (National Marine Fisheries Service enforcement agents and the U.S. Department of the Interior parks personnel), and colleagues participating in the Northwest Marine Mammal Stranding Network. Most of the information for this paper is on file at the Oregon State University's (OSU) Hatfield Marine Science Center in the form of stranding reports and collection records. Some of these occurrences have been reported through the Smithsonian Scientific Event Alert Network (SEAN), but often without the cause of death completely diagnosed. Many of the dead pinnipeds were held in frozen storage after collection for later examination. Many necropsies were performed by R. Stroud, J. Harvey, and R. Brown. In general, most rates of encounters were extremely low and, whenever possible, these are estimated in this text with the number of observer hours or thousands of animals observed.

CETACEANS

Lines

Gray whales have been the most common cetacean involved with fishing gear along the Oregon coast, probably as a result of the large number of individuals found nearshore, compared with other species. Approximately 16,000 gray whales annually pass the coast twice each year. The most frequent entanglement problem since 1968 was associated with experimental

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

crab fishing with helicopters in a short period from 1976 to 1978. Conventional commercial crab pots were fitted with the usual line and two surface buoys. The buoys were separated by a longer length of line to facilitate hooking them from the helicopter (particularly in heavy seas). This gear was often fished closer to shore early in the season because of high seas from winter storms. Most problems occurred during good weather when gray whales tended to migrate closer to shore in shallow water (Herzing and Mate 1984). Entanglements invariably involved the rope between the two floats getting caught between the baleen plates (probably during surfacing), and often became complicated by further entanglement of the flukes or pectoral flippers. I have seen the latter occur when the animal was making sharp turns, in an apparent effort to dislodge the rope. Between five and eight entrapments were reported during each of the helicopter crabbing seasons of 1975-76 and 1976-77. Problems have continued even after helicopter crabbing ended. Vessel-based crabbers move their gear closer to shore during the spring as weather improves and the crabs start to reproduce in shallow water (D. Snow pers. commun.). An average of two whales each year are now reported entangled in crab pot lines along the central Oregon coast. The fate of these animals is unknown, although in February 1977 an adult female gray whale was found beach cast with a conpicuous fracture of the coccygeal vertebrae (tail stock) and associated wounds, which were diagnosed as the principle cause of death (Stroud 1978). A beach cast minke whale collected in 1982 had a crab pot line through its mouth which had worn through the soft gum tissue and 2 cm into the jaw bone. The adult specimen was not fresh enough to discern whether other factors had also contributed to its death (J. Harvey pers. commun.).

I have a video tape taken by fishermen in 1982 showing a similarly entrapped humpback whale towing king crab gear in Alaska. The whale made an enormous effort to keep at the surface, swimming with its head out of the water at a 30° to 45° angle. In spite of this exertion, it was able to swim evasively at over 5 knots for at least 15 min to avoid the fishing boat, which was finally able to catch the dragging lines and cut the whale free. The rope was shorter than the water depth and was still attached to three crab pots.

During four seasons (1977, 1980, 1983, and 1984) of studying gray whales in San Ignacio Lagoon, Baja, Mexico, OSU crews have spent 6 months in this winter calving area and have seen five gray whales entangled in lines. Four of these have been calves, which may favor the shallower water where fishermen try to maintain modest winter fishing activities.

Nets

From 1975 to 1984, I am aware of only three net entanglements in Oregon, all involving gray whales. Two incidents involved gray whales in Columbia River gill nets: One was a live whale which subsequently died, and a second was an animal that had recently died and drifted into the net. A third incident, involving a yearling gray whale during August 1981, was investigated by OSU graduate student J. Sumich. He worked from a U.S. Coast Guard vessel to untangle most of a monofilament salmon gill net from a gray whale off Newport, Oregon (unpubl. data). The net was subsequently identified as being from southeast Alaska and was most likely brought south by the whale, which appeared quite fatigued. Only a few strands of net were left on the whale. No whales with net marks were subsequently reported ashore through the SEAN system in the next several months.

Boat Encounters

Annually, several instances of gray whales rubbing against anchor chains or boats are reported to the Marine Science Center by local salmon fishermen or sail boaters, but I am only aware of two instances where the whale hit the boat hard. Both times, people on board the vessels (without engines running) were watching gray whales and the whale was apparently unaware of the boat before striking it "accidentally." In my experience, whales react quickly and forcefully when unexpectedly "touched." Such a reaction has survival value for an animal preyed upon by sharks. I have also seen two gray whales blunder into floating logs with the same reaction. Boats also strike whales. A 10.7-m dead gray whale, examined at Cape Mears, had been struck by a vessel. There were large, evenly spaced, serial lacerations from a propeller, which cut through the blubber and into the muscle. There were also numerous shark bites up to 48 cm across, but these did not overlap sufficiently with the lacerations to determine which had occurred first. It is not known what caused the animal's death. It may have been dead before being hit by the boat, although the carcass was reasonably fresh.

Beach Cast

I am not aware of any cetaceans which have died as a direct result of debris in Oregon. However, it is worth a note of caution on the interpretation of death rates from beach cast animals. Unless the animal has died very close to shore, the likelihood of it becoming beach cast in Oregon is quite small. Currents and winds vary to affect the beaching of dead animals. A narrow shelf and a relatively steep continental slope reduce the chances of a whale, which dies offshore and sinks, from washing ashore. In Oregon, dead animals have washed up on rocky headlands, gently sloping sandy beaches and on mudflats in estuaries, but less than 10% have been in advanced stages of decomposition when they first came ashore. Most are fresh or only slightly bloated. Because the Oregon coast is so accessible, I believe that 90+% of the large whales which become beach cast are reported to the Oregon stranding network, although not always in real time.

Evidence of whales dying offshore is apparent from the frequency with which whale parts are reported or brought in by bottom-trawl fishermen. Most of what is brought ashore tends to be skull parts from large rorquals. The rollers on the bottom of trawl nets probably roll over small bones, which may also pass through the wide mesh of the trawl wings. Despite the fact that fishermen say they discard most of the whale material at sea, the Marine Science Center gets at least six calls each winter from fishermen wanting to donate unusually large specimens. Weathered whale parts can also be seen around the community. In most cases, it has been impossible to determine from the bare bones how long the whale has been dead. Thus, although trawl netting of whale parts may be 10 times more frequent than beach cast carcasses, the frequency of encountering the old material is at least partially the result of long-term accumulation. Old parts may also be renetted time after time because most fishermen dump them back into the sea. In 1984, the still oily skull base and lower jaws of a blue whale were recovered from a fisherman's trawl and were larger than 95% of all other known specimens of this species. There is no reason to believe that net-collected specimens died as a result of fishery interactions.

PINNIPEDS

Nets and Packing Bands

The pinnipeds most frequently encountering commercial fishing gear are seals on the Columbia River during active gill net fishing. The Washington Department of Fish and Game has collected considerable data on incidental take of seals since 1980. Although harbor seals do interact with other fisheries, I am not aware of seals being involved in any other fishing gear or debris-related mortalities in Oregon. In a 3-year study of 57 beach cast pinnipeds in Oregon, Stroud (1978) concluded that shooting was the leading diagnosable cause of death for adult harbor seals (7 of 16).

Steller and California sea lions have been observed with neck lacerations typical of net entanglement. During visits to three Steller sea lion rookery sites in June 1968, 2 animals (a female and an adult male), out of a total population of approximately 1,450, had visible neck lacerations. During the following 3 years, records were kept on individually recognizable Steller (n = 158) and California (n = 954) sea lions. Recognizable animals probably represented <10% of the animals using the areas surveyed throughout the year. Among the recognizable sea lions, 10 had open neck wounds (8 Steller and 2 California) and 2 (1 of each species) had healed neck scars. All neck wounded animals were all subadult males and females with the exception of one breeding male Steller. One of the open wounds was caused by a rusting metallic packing band. The healed California sea lion was seen on five occasions over a 2-year period. None of the others were resighted beyond the season in which they were described. The longest observation of an animal with an open neck wound was that of a subadult Steller over a period of 27 days during the 1970 breeding season. Of the 200+ pinnipeds examined by myself or OSU-based colleagues in 8 years, only one northern fur seal and one Steller sea lion have been found dead and beach cast with obvious net-induced neck lacerations. Both were emaciated. In 8 years, two additional live fur seals have been reported to the Marine Science Center as beached animals encumbered with net debris, but these were not confirmed. When fur seals come ashore in Oregon, they have most frequently been within 161 km (100 m) of the Columbia River.

Ingestion of Debris and Fishing Gear

One subadult northern elephant seal and one adult Steller sea lion choked to death on styrofoam cups (R. Stroud and B. R. Mate unpubl. data). We have also examined two pinnipeds which choked to death on fish.

Each year, it is common to see at least one Steller sea lion with a salmon troller's "flasher" (a chrome lure) hooked in its lip. These are almost certainly acquired during an encounter with an active fishing gear and not discarded gear. In 1969, a territorial Steller male had a troller's "flasher" in its lower lip for at least 7 days, before it was dislodged.

One of 38 sperm whale stomachs, examined from the stranding of 41 whales at Florence, Oregon in June of 1979 (Rice et al. in press), contained about 1 liter of tightly packed trawl net (J. Harvey unpubl. data).

SUMMARY

There does not appear to have been a dramatic observable increase in the occurrence of debris-induced marine mammal mortality in Oregon since 1968. The number of animals involved with debris appears to be low. Except for one instance of ingested netting by a sperm whale, cetacean associations with "debris" have been limited to fishing gear entanglements (with lines and nets). The most frequently reported involvements are gray whales towing buoy lines, most often caught in the mouth. Whales appear to be most vulnerable to the line between two buoys, often used by fishermen to mark and more easily recover stationary gear (traps, pots, and longlines). In all but one case involving whales and nets, the whale probably became entangled while the fishing gear was in use. If whale mortalities occur primarily offshore in Oregon, it is doubtful that much evidence from beach cast carcasses would accumulate. Pinnipeds have become entangled in active and discarded fishing gear and have also choked to death on swallowed debris and on fish. The observation of healed neck wounds on sea lions indicates that at least some individuals survive such ordeals. The low resighting of neck-wounded sea lions over a 3-year period may reflect one or more of the following: 1) a high mortality rate, 2) normal looking pelage concealing healed wounds, or 3) a failure to resight the animals during later census periods.

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